

OAK RIDGE NATIONAL LABORATORY

operated by
UNION CARBIDE CORPORATION

for the
U.S. ATOMIC ENERGY COMMISSION

PROCEEDINGS OF INFORMATION MEETING ON IRRADIATED WOOD-PLASTIC MATERIALS HELD AT CONRAD HILTON HOTEL, CHICAGO, ILLINOIS SEPTEMBER 15, 1965

Edited by:
Ralph E. Greene
Philip S. Baker

19960410 074

DTIC QUALITY INSPECTED 1

DISTRIBUTION STATEMENT A

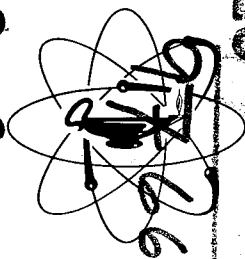
Approved for public release;

Distribution Unlimited

ISOTOPES INFORMATION CENTER

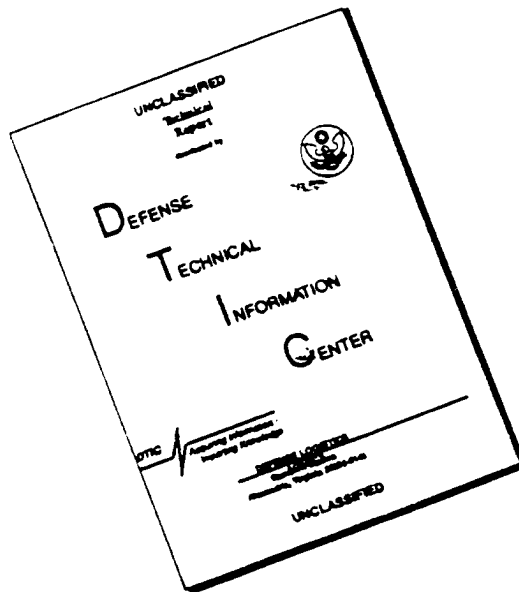
DEPARTMENT OF DEFENSE
PLASTICS TECHNICAL EVALUATION CENTER
PICATINNY ARSENAL, DOVER, N. J.

PL-9753-PL-9766



PLASTED 9753

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

Printed in USA. Price \$2.00. Available from the Clearinghouse for Federal
Scientific and Technical Information, National Bureau of Standards,
U.S. Department of Commerce, Springfield, Virginia

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ORNL-IIC-7
UC-23 -- Isotopes-Industrial Technology

Contract No. W-7405-eng-26

Isotopes Information Center

PROCEEDINGS
OF
INFORMATION MEETING
ON
IRRADIATED WOOD-PLASTIC MATERIALS
HELD AT
CONRAD HILTON HOTEL, CHICAGO, ILLINOIS
SEPTEMBER 15, 1965

Edited by:
Ralph E. Greene
Philip S. Baker

APRIL 1966

Sponsored by Atomic Industrial Forum in cooperation with U. S. Atomic
Energy Commission.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U. S. ATOMIC ENERGY COMMISSION

CONTENTS

	Page
The Atomic Energy Commission's Program in Wood-Plastic Materials Justin L. Bloom	1
Basic Research on Irradiated Wood-Plastic Combinations..... James A. Kent	69 9754
Polymerization and Polymer Properties as Related to Wood-Plastic Combinations..... Richard M. Klein	15 9755
A Testing Program to Investigate Certain Physical and Mechanical Properties of Selected Wood-Plastic Combinations..... Robert C. Gilmore	22 9756
Wood-Plastic Evaluation Program..... A. O. Burford	26 9757
A Progress Report on a Feasibility and Conceptual Design Study of the Wood-Plastic Combinations Process..... J. H. Frankfort	32 9758
Radiation and its Commercial Future..... Ernest B. Tremmel	49
Summary Report of Radiation Processed Wood-Plastic Materials.... Martin H. Stein	59 9759
Potential Applications of Irradiated Wood-Plastic Materials..... Burford B. Ruhl	64 9760
Irradiated Wood-Plastic Materials -- Commercial Possibilities in the Pacific Northwest (and the Great Lakes Region)..... C. A. Rohrmann	76 9761
The Investigation of Commercial Potential of Wood-Plastic Com- binations in the Northeast..... Douglas M. Egan	81 9762
Commercial Production of Wood-Plastic Combinations..... Lawrence G. Barrett	89
Development-Production Program for Lockwood..... G. M. Kalember	95 9763
The Opportunity for Commercial Use of Irradiated Wood-Plastic Materials in the Furniture Industry..... Paul E. Rumbaugh	99 9764

	Page
9765 Potential of Wood-Plastic Combinations in the Sporting-Goods Industry.....	106
Thomas R. Harris, Jr.	
9766 Potential Commercial Manufacture and Use of Hardwood Plywood Plastic Combinations.....	112
Clark E. McDonald	

PROCEEDINGS OF INFORMATION MEETING ON
IRRADIATED WOOD-PLASTIC MATERIALS
HELD AT
CONRAD HILTON HOTEL, CHICAGO, ILLINOIS
SEPTEMBER 15, 1965

The recent mushrooming interest in wood-plastic materials led to the one-day information meeting represented by the talks included in this compilation. With the concurrence of the Division of Isotopes Development of the U. S. Atomic Energy Commission and the Atomic Industrial Forum, the speakers were requested to make copies of their talks available for publishing; all agreed to do so. These Proceedings are the result.

It is to be noted that there are still incomplete answers to a number of questions. Although the basic principles have been pretty well worked out, several interesting yet perhaps fundamental details are lacking including, for example, the amount of grafting that occurs during polymerization, the long-range moisture resistance of the products, the feasibility of "casehardening" thin surface layers by partial impregnation, and better information on market potential and the economic factors involved. The economics, in particular, could be altered somewhat by the recent drastic reduction in the price of ^{137}Cs , which is an alternative radiation source.

We trust that the reader will find the Proceedings useful. The affiliations of the contributors are included with each paper for those who wish additional information.

Ralph E. Greene

Philip S. Baker

Editors

THE ATOMIC ENERGY COMMISSION'S PROGRAM IN
WOOD-PLASTIC MATERIALS

Justin L. Bloom*

ABSTRACT

Introductory remarks for the meeting are presented, and the Atomic Energy Commission's wood-plastic program is described. The four areas that constitute the program are (1) research on the fundamentals of the process and properties of the materials produced, (2) market surveys and commercialization studies, (3) consolidation of technical and economic information available and preparing conceptual plant design, and (4) cooperative agreements with a representative cross section of wood-products industries to provide consulting services to industry for specific products to be converted to wood-plastic combinations for evaluation purposes. Various contractors are performing the work of this program. The mission of the Division of Isotopes Development, i.e. expansion of the use of radiation and radioisotopes in applications which are in the national interest, is also briefly described.

Up to a few days ago, Mr. E. E. Fowler planned to be here to welcome you personally on behalf of the Atomic Energy Commission and the AEC Division which has supported the development of wood-plastic materials. However, urgent matters in Washington required his presence there, and he asked me to represent him. In Gene's absence, there is no danger in embarrassing him by pointing out to you that the rapid rate of growth of the AEC's interest in and support of the wood-plastics work has been due to his initiative and foresight. He personally has contributed enormously to both the planning of the program and obtaining funds for it. The latter function is never an easy job in Government, and most of us

*Chief, Radiation Applications Branch, Division of Isotopes Development, U. S. Atomic Energy Commission, Washington, D. C.

would rather be spared any responsibility in this direction. However, the interests of the taxpayer must be protected, both from the point of view of those who hold the purse strings and those who ask for funds to carry out projects which we believe to be in the national interest.

In our opinion, the AEC program studying the fabrication of wood-plastic materials by use of radiation falls within our definition of "national interest," and the best evidence of this is your attendance at this meeting. We have watched this program grow from a small-scale laboratory effort to a mature development project, primarily because it has captured the imagination of the public in general, and the wood products industry in particular. Our purpose in joining with the Atomic Industrial Forum to sponsor this meeting is to give you the opportunity to receive the latest information available on the process, without having to search through extensive technical documentation. At the same time, you will be able to meet and hear the prominent workers in the field — not only those within the AEC contractor family, but also those who are involved on a private venture basis. You will also get the considered opinions of several prominent representatives of the wood-products industry on the potential of the process in commercial applications.

By way of background, the AEC wood-plastics program has been organized into four areas which overlap to some degree. Supporting the entire effort is the research on the fundamentals of the process itself and on the properties of the materials produced. West Virginia University and Research Triangle Institute (in conjunction with North Carolina State University) are our contractors in this area.

Next, we have performed and are performing market surveys and commercialization studies to determine what the economic potential of the process might be and to assess the relative future roles of the AEC and industry. Our contractors include A. D. Little, Inc., the Southern Interstate Nuclear Board, Pacific Northwest Laboratories of Battelle Memorial Institute, and Western New York Nuclear Research Center. Third, we are consolidating the technical and economic information available and preparing a conceptual plant design to arrive at meaningful unit-cost projections for the process. Vitro Engineering Company is performing this work. Last, we have selected the Lockheed-Georgia Company to represent us in entering into cooperative agreements with a representative cross-section of the wood-products industry to enable the industry to obtain consulting services geared to specific products and to have these products converted to wood-plastic materials for evaluation purposes. Consideration is also being given by the Commission to the desirability of a more extensive program between government and industry, but no firm conclusions can be drawn as to the nature of this relationship at this time. For one thing, we need the results of the various studies now in progress before we can make firm judgments.

It is not often that I have the opportunity to speak to a large group such as this one, and I would like to recognize the contributions of a few people in making this meeting necessary and possible. Martin Stein, who will be the session chairman this afternoon, is our manager of the process radiation programs in the Division and, as such, has been involved in the wood-plastics project from its inception. His

enthusiasm, competence, and organizational ability have been instrumental in keeping the work moving forward at a rapid rate. George Dietz, who was unable to be here today because he is delivering a paper at the American Chemical Society meeting in Atlantic City, has performed in equal fashion by handling facilities and radiation source requirements for the process radiation program and managing the several commercialization studies on wood-plastics material which we have underway.

I think that many of you realize that the AEC differs from most other Federal agencies in that it does not conduct research with its own personnel. Its work is performed by contractors; these may be universities, private industrial organizations, or nonprofit institutions. In the wood-plastics program we have been blessed with contractors, representing all these groups, who have performed with commendable proficiency. I want none of them to relax in their efforts, but we recognize that we have been getting more than our — and your — money's worth from them. Although they all deserve recognition and credit, I will single out Dr. James Kent of West Virginia University for special mention, since he is the pioneer worker in the field. He has never lapsed in his eagerness to develop wood-plastic formulations and to study the properties of these materials.

Since the large majority of those present are not directly involved in the atomic energy business, perhaps it is appropriate that I say a few words about the overall role of the Division of Isotopes Development. Our mission in life is to expand the use of radiation and of radioisotopes in applications which are in the national interest and hence which cover the gamut of human activity in this country. Aside

from our basic function of developing new isotopes and producing them in quantities sufficient to meet the nation's needs — a function that is being assumed more and more by industry as time goes on — we are supporting developmental activities which cover their use as heat sources in small power supplies for space, terrestrial, and underwater missions established by other Government agencies; as large radiation sources for the induction of chemical reactions and for the preservation of food; and as tools in the hands of the scientist and engineer for solving problems of measurement and control in a broad variety of industrial, environmental, and governmental systems. At the present time we administer some 80 contracts for these purposes. My own responsibilities cover the general management of the process radiation, food preservation, and isotopes systems programs.

In conclusion, let me express the thanks of the Division and of the AEC to Ed Wiggin of the Atomic Industrial Forum for performing a yeoman's job in arranging this Conference and for his interest in our work, and to all of you for your attendance and cooperation.

9754

6

BASIC RESEARCH ON IRRADIATED WOOD-PLASTIC COMBINATIONS

James A. Kent*

ABSTRACT

The basic steps--evacuation, impregnation, and irradiation--for the preparation of samples of wood-plastic combinations (WPC) for physical testing are briefly described. These tests have shown WPC to have general improvements in toughness, bending and compression strength, hardness, moisture resistance, abrasion resistance, shear strength, insect and rot resistance, workability, and other properties. In a comparison of methods to induce polymerization of monomers within wood, irradiation is shown to have several advantages over heat: absence of a catalyst within the monomer, which prevents danger of premature polymerization and loss of valuable monomer; enhanced safety of operation; and better control of the rate of polymerization.]

My remarks will be directed toward a basic description of the radiation process for wood-plastic combinations. First, wood of the desired species is cut to size and weighed. Next, it is placed in with a cylindrical chamber of 5-inch pipe about 30 inches long (Fig. 1), which is then evacuated to an absolute pressure of about 1 or 2 mm Hg. The evacuation serves two purposes: (1) it removes air from the pore spaces of the wood to make room for the liquid monomer; and (2) it eliminates most of the oxygen from the wood. Oxygen has a marked inhibitory effect on the subsequent polymerization and requires the expenditure of excessive radiation. While the system is still under a vacuum, sufficient monomer is introduced into the chamber to completely cover the wood. It might be appropriate to mention that many of the more important monomers have the general appearance and consistency of water. However each one has its own characteristic odor which is, in some cases, very strong and disagreeable.

*West Virginia University, Morgantown, West Virginia.

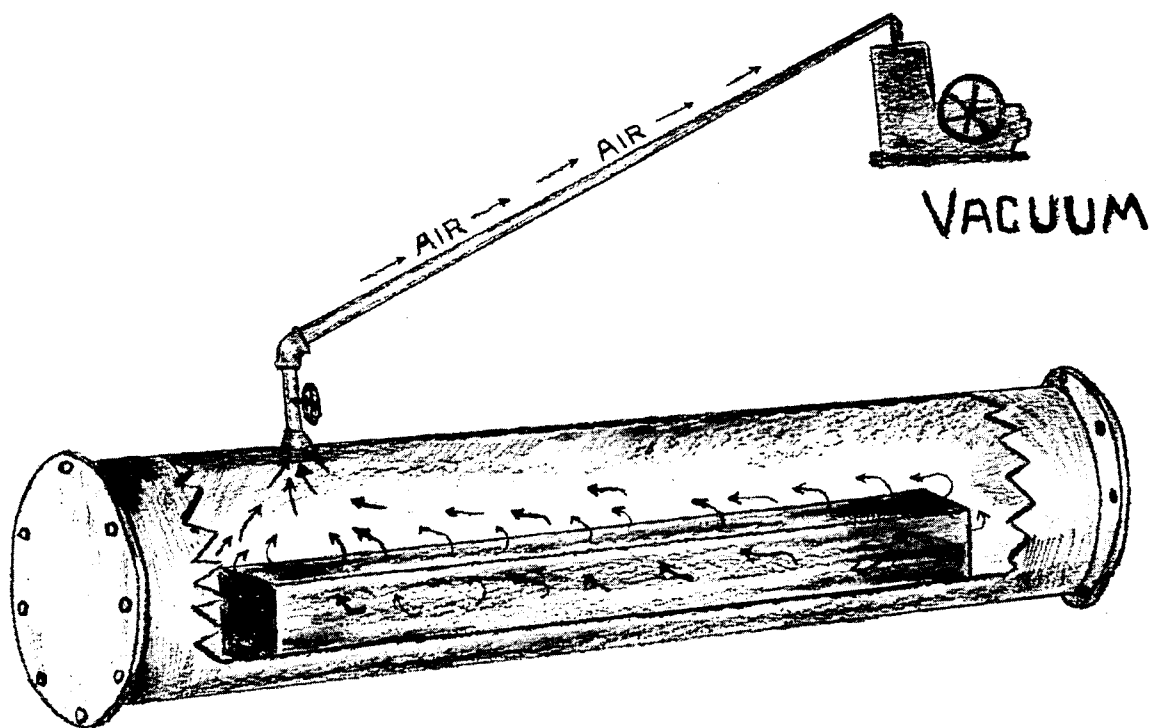


Fig. 1. Evacuation.

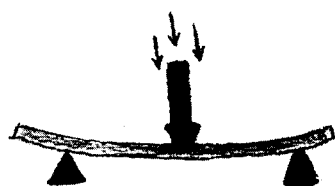
One monomer with which we have worked extensively is methyl methacrylate; its polymer is commonly known as Plexiglas or Lucite.

After the introduction of the monomer, nitrogen gas is admitted into the chamber to atmospheric or higher pressure and the wood is allowed to soak for a predetermined time. A large number of combinations of evacuation treatments and pressures may be used to control the amount of monomer which enters the wood. The next step consists of draining the unabsorbed monomer from the impregnation chamber. The wood is then removed and weighed to determine the amount of monomer it has absorbed and is loaded next into a suitable container and placed in a field of gamma radiation of desired intensity. It is during this exposure to radiation that the liquid monomer polymerizes to a solid plastic.

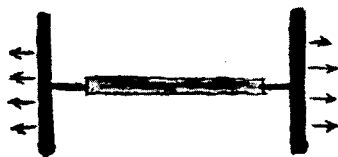
Finally, the completed wood-plastic combination is removed from the irradiation container, reweighed, and cut to final size for the required testing procedures.

A variety of tests are performed on the experimental WPC (Fig. 2). These include toughness (impact resistance), bending strength, compressive strength, hardness, water absorption, abrasion resistance, shear strength, insect and rot resistance, and others that may be required.

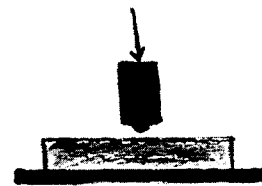
We have shown through tests conducted in our own and in other laboratories general improvements in all of the properties just mentioned. For example, the relative toughness of white pine containing poly (methyl methacrylate) increases linearly with increasing plastic content; the toughness of white pine containing about 1.6 pounds of plastic per pound of wood is about twice that for unmodified white pine



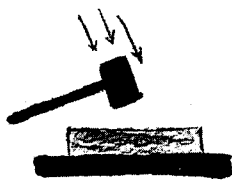
STATIC BENDING



TENSION



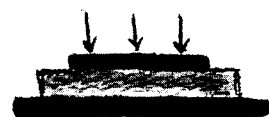
HARDNESS



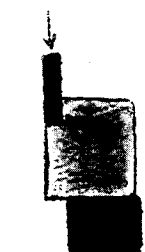
IMPACT



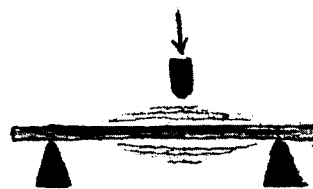
ABRASION



COMPRESSION



SHEAR



VIBRATION

Fig. 2. Physical Property Tests.

(Fig. 3). Likewise, the value of abrasion resistance of sugar maple containing 0.6 pound plastic per pound of wood was four times that of sugar maple alone. The proportional limit and crushing strength of WPC are significantly better than the corresponding values for unmodified wood. For example, an improvement of about 50 per cent was realized with sugar maple containing about 0.5 pound of plastic (copolymer of styrene and acrylonitrile) per pound of wood. Finally, the hardness of sugar maple, a species which is naturally hard, was increased by 300 per cent by the addition of 0.6 pound of poly (styrene/acrylonitrile) per pound of wood (Fig. 4).

I should comment briefly regarding the workability of WPC. They can be sawed, turned, drilled, and sanded in much the same way as unmodified wood using conventional woodworking equipment. There is, as one might expect, a decrease in nailability. This is occasioned by the increased density which means that the wood fibers have less space in which to move to make way for a nail. However, many potential large volume uses do not require nailing. Where nailing is required, the use of lead holes can overcome the problem.

An attractive finish results from sanding WPC with a fine sandpaper, followed by buffing with cloth. The finish has a high lustre and, when damaged, can be easily renewed by light sanding and buffing.

A wide spectrum of uses is possible based on the properties of WPC. Their mar resistance and attractive, renewable finish make them well suited for use in furniture, while improved moisture resistance and impact resistance recommend them for use in sporting goods. Tests so far indicate a substantial improvement in abrasion resistance so that

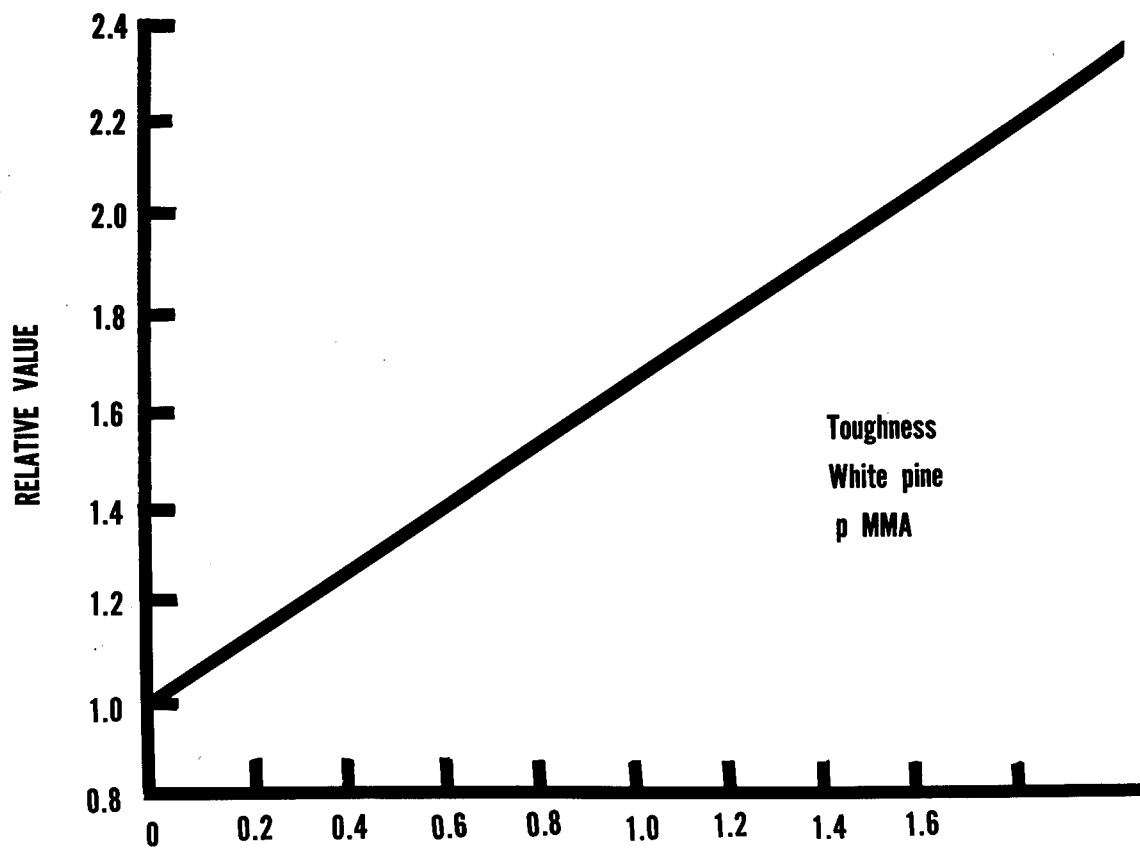


Fig. 3. Polymer Loading, 1b Polymer per 1b Wood.

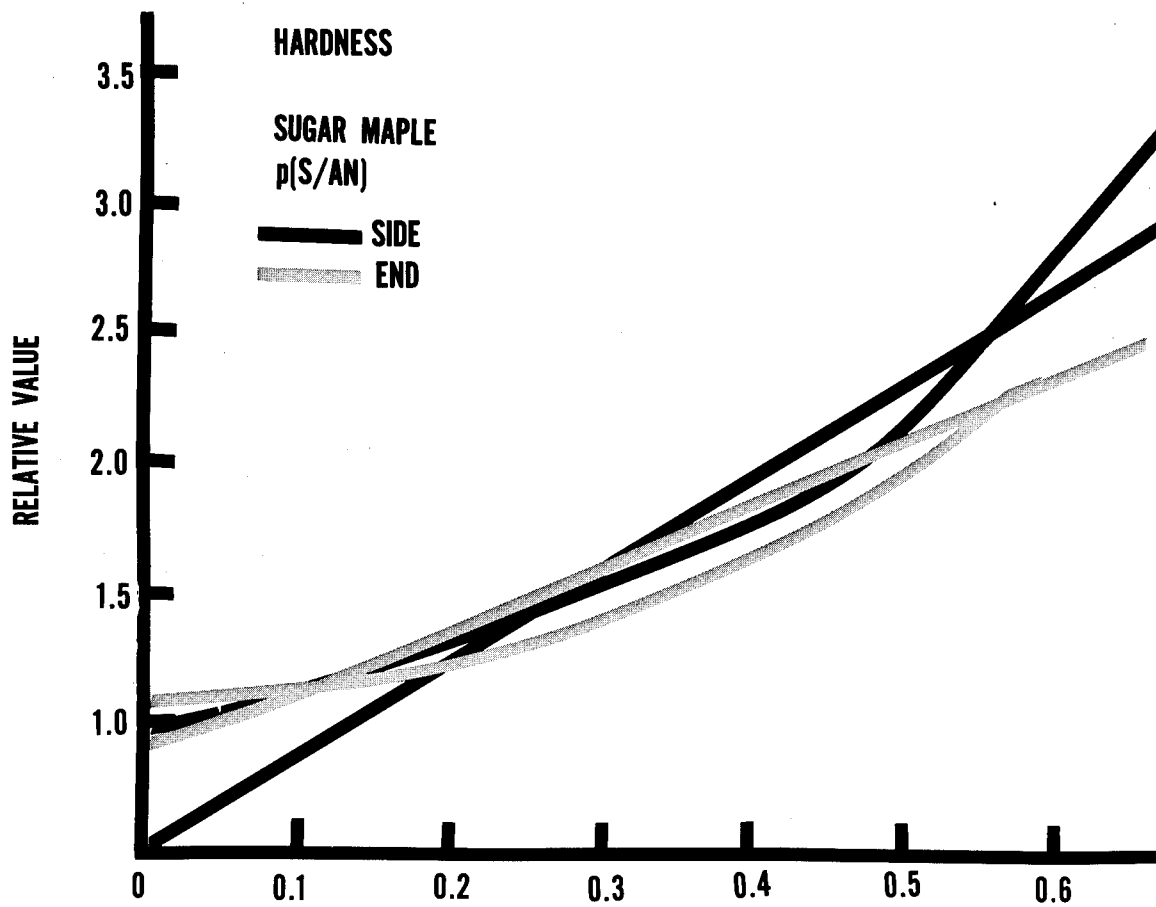


Fig. 4. Polymer Loading, 1b Polymer per 1b Wood.

utilization in flooring may be practical. Jigs, dies, patterns, and similar industrial items comprise still another area of potential application. The uses to which WPC will be put will be limited only by the ingenuity and imagination of the industrial community.

There is one additional matter which I should like to discuss. Since the very beginning of our work on radiation-processed WPC, the question has been raised as to whether or not these materials can be prepared using heat and catalysts. The answer is in the affirmative. Many individuals working in many laboratories have made WPC in this way. However, during the span of several years, no commercial use has been made of such processes. This is due in large part to the hazards and materials handling problems which would be encountered in a production unit.

One such problem involves the handling and storage of monomers which contain a catalyst. One must bear in mind that catalyst would be dissolved in the monomer solution prior to the time that the solution was introduced into the impregnation vessel. Thus, the monomer in the tank in which the addition of catalyst is performed (measured in thousands of gallons for a commercial process) would be susceptible to premature polymerization. The same situation would exist in the impregnation tank during the time that the wood is being impregnated. If some event such as a slight temperature rise occurred to trigger the polymerization, it could proceed very rapidly with attendant rapid evolution of heat and pressure rise. Thus, in addition to the loss of costly raw materials, real hazards to safety would exist.

One further point involves control of the polymerization reaction in wood and, by the same token, the rise in temperature and pressure. In the catalyzed process, heat must be applied to cause the reaction to proceed but it must also be removed to prevent an excessive temperature rise. The difficulty of maintaining control of the reaction (which is temperature dependent) is obvious.

The radiation process overcomes the problems cited above. A catalyst is not required and, in fact, the monomer solution can be stored and used with a suitable inhibitor so that the danger of premature and uncontrolled polymerization is nil. Controlling the rate of polymerization in the wood is also easy. One simply adjusts the radiation dose rate. Also, during radiation polymerization, the heat of reaction can be removed by using cooling water on the irradiation containers.

There are many cases recorded where a radiation process has been "edged out" for various reasons, not all of them valid, by so-called "conventional" techniques. This will not be the case with WPC. The advantages of the radiation process are much too numerous and obvious.

POLYMERIZATION AND POLYMER PROPERTIES AS RELATED TO
WOOD-PLASTIC COMBINATIONS

Richard M. Klein*

ABSTRACT

[The basic mechanism of polymerization of a monomer is briefly described. There are four advantages of using radiation rather than chemical catalysts to induce this polymerization reaction in wood: (a) pot life of the monomer is longer; (b) radiation can overcome effects of resins in the wood that act as inhibitors for chemical catalysts; (c) elevated temperatures and long curing times are not required with irradiation; and (d) no chemical catalyst residue remains in the wood. Three types of polymerization reactions are discussed: (a) graft polymerization between polymer and cellulose; (b) cross-linking of polymers; and (c) copolymers formed from two or more different monomers.] The glass transition temperature, a useful parameter for qualitatively estimating mechanical properties of homopolymers and copolymers, together with its application to copolymer systems, is explained.

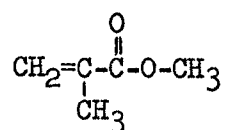
INTRODUCTION

The purpose of this paper is to discuss polymers (or plastics) and their properties as they pertain to wood-plastic combinations. It is a general feeling that only the surface has been scratched with respect to the many possible varieties of wood-plastic materials. Within the existing technology of wood-plastic combinations (WPC), products having a wide spectrum of mechanical characteristics could result—as much from varying the composition of the plastics that are formed within the wood as from varying the type of wood itself. Thus we should consider the present wood-plastic materials only as prototypes.

*Manager of Sales Development, Special Products Department,
Rohm & Haas Company, Philadelphia, Pennsylvania.

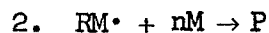
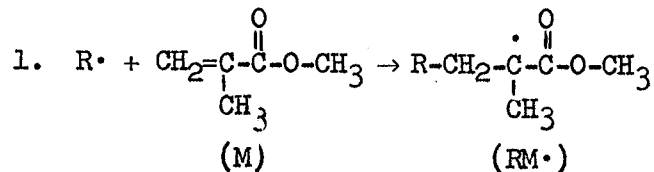
MONOMERS AND POLYMERIZATION

In wood-plastic combinations, the monomer is the chemical that impregnates wood and forms the basic building blocks of the plastic (polymer) produced by irradiation. By far the most useful monomer to date for producing wood-plastic alloys is methyl methacrylate (MMA), a member of the family of acrylic monomers and polymers on which this discussion is based. The structure for methyl methacrylate is shown below.



Other monomers that have been investigated for commercial possibilities in WPC include styrene, acrylonitrile, and vinyl acetate. These all contain the same type of vinyl unsaturation as does methyl methacrylate; but due to the combination of excellent response to radiation, relatively low heat release on polymerization, and lustrous physical appearance, MMA holds a distinct advantage over these other materials for commercial production of WPC.

The basic process by which a monomer is built up into a polymer is shown schematically below:



The R· represents an initiator radical, M the monomer, and P the polymer. In the formation of wood-plastic combinations the initiator radical R·

is produced by action of the high energy radiation on the monomer itself, the wood cellulose, or the impurities in wood.

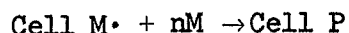
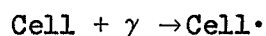
In other polymerization systems, radicals may be formed when an unstable chemical molecule, such as a peroxide, decomposes into free-radical fragments. However, certain advantages inherent with the use of radiation as the catalyst should be considered in the WPC process.

First of all, with no chemical catalysts initially in the monomer, the possibility of premature polymerization before impregnation (short pot life) is eliminated. Second, wood contains resins which act as polymerization inhibitors. Chemical catalysts in the impregnated monomer can be consumed by these inhibitors and the desired polymerization reaction may not proceed. With radiation, the catalyst supply is continuous, and thus the effect of the inhibitors is overcome. Third, chemically catalyzed systems frequently require elevated temperatures for extended times to cure completely, and this could result in monomer loss through volatilization as well as being detrimental to the wood. The present WPC system is initiated at room temperature. Finally, radiation leaves no chemical catalyst residues in wood that might deteriorate or cause deterioration on aging. These comparisons of chemical vs radiation curing are summarized below:

RADIATION VS CHEMICAL POLYMERIZATION IN WOOD

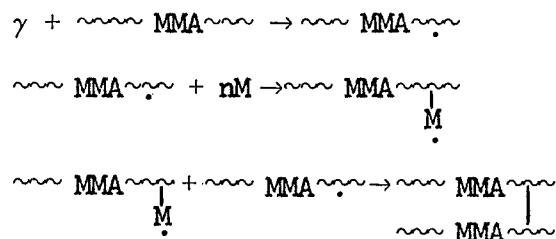
RADIATION	CHEMICAL
Unlimited pot life	Reduced pot life
Continuous - will overcome inhibitors in wood	Affected by inhibitors in wood
Begins at room temperature; no heating required	Requires high temperatures for extended times
No catalyst residues	Catalyst residues in wood

Three other types of polymerization reactions that can take place in the WPC system should be mentioned. Radiation will produce radicals on wood and these can react with methyl methacrylate monomer to produce graft copolymers as depicted below:



The term cell represents wood cellulose. In this reaction a chemical modification of the wood structure actually occurs and may impart desirable and unique properties to the product.

Second, radiation will initiate additional radicals on the methyl methacrylate polymers which can react with other monomers or polymers to give crosslinked material as shown below:



The resultant higher molecular weight could impart added hardness, toughness, and solvent resistance to the composition.

Third, other monomers can be introduced into the wood along with MMA, which will react to form copolymers with a variety of properties. This leads to the next section on properties of polymers.

POLYMER PROPERTIES

When polymerized alone in bulk, methyl methacrylate becomes a hard, clear plastic material known commercially by the Rohm & Haas trademark

as Plexiglas. A useful parameter for qualitatively estimating several mechanical properties of homopolymers and copolymers is the glass transition temperature (T_g). This is the temperature at which the polymer changes from a hard, glassy material to a soft, rubbery material. In general, the higher the T_g of a polymer, the greater the hardness, modulus of torsion, and tensile strength, and the lower the elasticity and elongation. Abrasion resistance is also related to the T_g . A table of T_g values for common homopolymers is shown below:

<u>Polymer</u>	<u>T_g, °C</u>
Methyl methacrylate	105
Styrene	100
Acrylonitrile	96
Vinyl acetate	30
Butyl methacrylate	20
Ethyl acrylate	-22
Butyl acrylate	-54

Of particular utility is the relationship between the T_g of copolymers (T_{co}) and the T_g of the constituent monomers and the monomer weight fractions. This relationship is expressed by the formula

$$\frac{1}{T_{co}} = \frac{W_1}{T_1} + \frac{W_2}{T_2} \dots + \frac{W_n}{T_n} ,$$

where W is the weight fraction of the individual monomer and T is the T_g in °K. A useful Glass Temperature Analyzer Card for calculating T_g of common copolymer systems is available (1).

Copolymerization of different comonomers, or of the same comonomers in varying proportion, produces copolymers with different T_g and hence different mechanical properties. The changes in mechanical properties of some acrylic polymer films of different T_g are shown below:

T_g , °C	Hardness, Shore A ₂	Modulus of Torsion 20° C , kg/cm ²	Tensile Strength, psi	Elongation, %
-32	15	0.1	260	960
-1	32	4.3	620	1120
17	62	65	1250	600
33	94	5000	3200	280
85		8500		

Considering these data, it can be inferred that the mechanical properties of wood-plastic combinations will be related to the T_g and the other properties of the impregnating polymer. In addition, greater moisture resistance might be built into the WPC by use of hydrophobic monomers such as stearyl methacrylate or vinylidene chloride. A whole new area of application could open up in outdoor uses, and here the acrylics show excellent long-term durability on exposure.

This is why it was said earlier that the surface has only been scratched as far as properties and performance of wood-plastic combinations are concerned. It is likely that specific properties can be engineered into the system to suit various end-use requirements. Combinations of methyl methacrylate with monomers such as butyl and stearyl methacrylate or methyl and butyl acrylate should modify the overall abrasion resistance, hardness, impact strength, nailability, toughness, weathering resistance, etc., of the WPC.

Thus careful consideration and evaluation of today's prototype wood-plastic materials, even for applications where their physical properties may not be completely satisfactory, is warranted.

REFERENCE

1. Bulletin SP-222, Rohm & Haas Co., Special Products Department, Philadelphia, Pennsylvania.

A TESTING PROGRAM TO INVESTIGATE CERTAIN PHYSICAL AND
MECHANICAL PROPERTIES OF SELECTED WOOD-PLASTIC COMBINATIONS

Robert C. Gilmore*

ABSTRACT

[A testing program to evaluate physical and mechanical properties of wood-plastic combinations will be conducted under AEC sponsorship through the combined efforts of North Carolina State University, The Research Triangle Institute, and the West Virginia University Engineering Experiment Station. The objective of the program is to assess the changes in certain physical and mechanical properties of WPC as functions of monomer and monomer loading.] Four monomers at four nominal loadings, 0%, 33%, 66%, and 100%, will be used. [The program will include static bending, hardness, toughness, abrasion, rate of dimensional change relative to humidity, compression, tension, and vibration tests.]

North Carolina State University, The Research Triangle Institute, and the West Virginia University Engineering Experiment Station have combined talents to investigate certain physical and mechanical properties of selected wood-plastic combinations. This project is being supported by the Division of Isotopes Development of the AEC. The Research Triangle Institute has the responsibility of liaison among the agencies involved, the statistical design of the study, and the analysis of the results. The Wood Products Laboratory of the School of Forestry at N. C. State University is responsible for the collection and preparation of test specimens for treatment and for the evaluation of the physical and mechanical testing of the specimens after impregnation and irradiation. The University of West Virginia, under the direction of Dr. Kent, will impregnate, irradiate, and prepare the treated specimens for testing.

* Superintendent, Wood Products Laboratory, North Carolina State University, Raleigh, North Carolina.

The objective of this program is to assess the nature and extent of changes in certain physical and mechanical properties of wood-plastic combinations as a function of both monomer and monomer loading.

Four species of wood were selected for this study on the basis of their commercial importance and, to some extent, their density. The two hardwoods selected were northern red oak (a high density species) and yellow poplar (low-medium density species). All of the specimens from these two species are to be taken from the heartwood. The two softwoods selected were loblolly pine (high density) and eastern white pine (low density). All of the specimens taken from loblolly pine came from the sapwood while those of the white pine came from the heartwood. Since the heartwood and sapwood of almost all species react quite differently to the penetrability of liquids, special effort was made to restrict specimens to the heartwood or sapwood zones mentioned above.

The four monomers initially selected were methyl methacrylate, styrene acrylonitrile, vinyl chloride and vinyl acetate. Some difficulties have been encountered with vinyl chloride and vinyl acetate during the preliminary trials, and other monomers may have to be substituted. Four nominal loadings will be applied to each species of wood. These will be 0%, 33%, 66%, and 100% or full (maximum) loading. The 0% loading serves as our control or untreated specimen.

The following tests are to be performed:

1. Static bending
2. Hardness
3. Toughness
4. Abrasion

5. Rate of dimension change as a result of exposure to humidity
6. Compression perpendicular to the grain
7. Tension perpendicular to the grain
8. Vibration characteristics.

This series of tests is much more comprehensive than earlier work, both in the number of tests and the variety of wood-plastic combinations to be used with matched specimen materials. Initially, North Carolina State University planned to obtain all the required material from two trees of each species, but we have already found it necessary to add a third tree for yellow poplar. In cutting our samples we have sawed the logs into planks which will yield a group of 16 specimens. These 16 specimens (referred to as a group) provide us a matched set, since they are located at the same radial position in the tree and within a relatively short vertical distance. Within this group, specimens are randomly selected for treatment with one of the four monomers at one of the four levels of loading.

The number of groups required for each test reflect to some extent the variability of that particular test. Since toughness is a property with high variability, we are repeating or replicating that test eight times within a species. The larger volume of data collected for these more variable tests (such as toughness) provides the statistician with sufficient information to predict a true average of the strength of the tested material.

It should be realized that the tests to be conducted in this study are not all-inclusive. Other tests could be proposed to determine other fundamental properties and certain characteristics that might be advantageous for particular applications.

What will these test results show us? The static bending tests will indicate the stiffness and breaking strength of the various wood-plastic combinations at different levels of loading. This information is of value to the structural designer and therefore to the construction industry. It can also be of use to the furniture manufacturer and designer since a substantial change in strength properties could permit a change in furniture design and construction. Changes in toughness values because of treatment should be of interest to manufacturers of certain lines of sporting goods, tool handles, etc. Abrasion resistance and hardness tests should provide information of value to flooring and furniture manufacturers. Results of compression tests perpendicular to the grain would probably be of interest primarily to the structural designer. Tension tests perpendicular to the grain would yield information related in some degree to cleavage tests and also to other limitations such as end splitting or checking associated with wooden furniture. The tests involving dimensional rate of change relative to humidity changes should be of interest to most users of wood, and especially those in flooring and furniture manufacture. The vibration tests are not widely used yet, but they will reveal

- (1) information that can be related to stiffness,
- (2) the damping characteristics of a piece of wood (or wood-plastic combination) to vibrational energy,
- (3) information that may be useful in nondestructive testing of wood and wood products.

WOOD-PLASTIC EVALUATION PROGRAM

A. O. Burford*

ABSTRACT

A program for the wood-products industry to evaluate production samples of radiation-produced wood-plastic combinations (WPC) for commercial use is described. Under contract with the USAEC, the Lockheed-Georgia Company will provide impregnation and irradiation services for 78 participating wood-product producers. Evaluation criteria that were used for selection of the 78 of 181 competing companies were based on the product wood species, market potential, dimensions, increased cost, etc. A breakdown of the various types of products and the bases for evaluation of their applicability for commercial use are also included.]

The Atomic Energy Commission issued an invitation on July 16, 1965 to the wood-products industry to participate in a program for the evaluation of radiation processed wood-plastic combinations (WPC). This invitation specified that interested companies should submit requests for participation in the program to the Lockheed-Georgia Company, Georgia Nuclear Laboratory, at Dawsonville, Georgia, prior to August 20, 1965. Under provisions of this program, companies selected by the AEC will submit wood samples for impregnation and irradiation by Lockheed-Georgia Company. Participating companies are expected to fabricate end products from their wood-plastic samples and to submit an evaluation report on the suitability of this new material for their products.

EVALUATION CRITERIA

One hundred and eighty-one responses were received from the AEC invitation and were classified into 24 categories to provide representation

*Manager, Nuclear Analysis Department, Lockheed-Georgia Company, Marietta, Georgia.

in the program from the largest possible cross section of the wood-products industry. Products and firms were selected from each category to ensure that products having the greatest potential in wood-plastic applications were included in the program. The following considerations were used in making the selections:

1. Wood Species

Certain wood types do not impregnate well and consequently do not produce a satisfactory product. Not all inquiries specified wood type; some listed multiple types which included both acceptable and nonacceptable wood species; others listed species with unknown impregnation characteristics. In these cases consultation with the companies concerned resulted in either a resubmission of a sample of suitable wood type or elimination of the product from the program.

2. Market Potential

Products representing the largest market potential for WPC were given priority. Special consideration was given to those products representing existing markets, rather than to those representing future markets, to expedite the commercialization of WPC. In general, end-product manufacturers were selected rather than wood suppliers.

3. Multiple Responses Within the Same Category

Many responses for processing similar items were received; however, multiple evaluations were essentially excluded to provide the widest possible cross section of the wood-products industry.

4. Dimensions of Specimens

All products selected were required to have dimensions which would allow the sample to fit within the existing Lockheed facilities which can

accommodate items up to 6 ft in length. Although some companies did not specify dimensions of their specimens and some expressed a desire to have material processed which exceeds the dimensional capacity of the Lockheed equipment, the problems were resolved by consultation with these companies.

5. Effect of Increased Cost on Wood-Plastic Product

The considerable enhancement of physical and esthetic properties exhibited by WPC is not required for all products, nor do the improvements in all cases justify the increased cost. When it appeared that the cost would be excessive for products, companies were contacted for their opinion. Several potential participants were eliminated at their own request for this reason. Economic data generated by Vitro Engineering Company for the AEC on the cost of producing WPC were used in these discussions.

EVALUATION RESULTS

Of the 181 companies requesting participation, approximately 78 were selected by the AEC. The number and predominant areas of the various responses were as follows:

1. Thirty-two responses were received from furniture manufacturers and covered a wide variety of uses including industrial, commercial, outdoor, and home furniture.
2. Fifteen companies were interested in veneer or plywood application. A number of companies in other categories, such as furniture and cabinet manufacturing, were also interested in veneer applications, but those companies were included in their respective categories.
3. Thirteen companies were interested in flooring applications.
4. Twelve companies manufactured sporting goods and another six companies requested processing for gun stocks.

5. Twelve responses were received from companies producing millwork, including doors and windows.
6. Ten responses were received from companies producing handles.
7. Twenty responses were received from various industries, almost all of which represented different industrial uses.

The responses to the AEC invitation were not entirely random. Both the AEC and the Lockheed-Georgia Company sent press releases of the contract announcement to companies which had indicated interest in WPC by previous communications. In addition, there were standard public information releases which appeared in various trade journals. Most of the responses were received from companies which had received the AEC announcement directly. The geographic distribution of the responding companies was quite good and at least one response was received from essentially every state which has a sizable wood fabrication industry.

Evaluation of responses revealed that, while most of the companies responding had a general knowledge of these materials, it was evident that the details of cost, physical characteristics, and availability were not well understood. It appears from Lockheed's evaluation of responses and consultations that a true evaluation of wood-plastic material will be achieved only by the wood-using industries working with these materials to produce their own product.

PROCESSING

Each of the companies selected by the AEC to participate in the wood evaluation program will be contacted concerning the wood species and wood forms to be processed. From these contacts a detailed processing plan will be developed. Processing should begin in October and continue through

November, 1965. An effort will be made to process, first, specimens which require a long testing period for end-product evaluation. Throughout the treatment and evaluation period the contractor will be in contact with each of the participating companies to give whatever assistance and consultation are required. Because of the large number of selections, the scope of the program will probably not permit as much to be processed as some groups might desire. Generally, the quantity of wood to be processed for a manufacturer will be adjusted according to his needs; for example, larger quantities of wood for flooring and furniture will be prepared than for cutlery handles. Since the contract provides for the processing of 6000 to 8000 pounds of wood (at 5 or 6 pounds per board foot), then each company should received enough material to reach some firm conclusions concerning the use of WPC in its products.

EVALUATIONS

The prime objective of the proposed program is the evaluation of the applicability of radiation processed WPC to commercial use. To permit a realistic assessment of industrial acceptance and potential utilization of these materials, each participating company will be requested to submit to Lockheed an evaluation report on the suitability of each material processed for a specific end-product application. All companies will be asked to submit certain standard data from their evaluations:

1. A description of the testing and evaluation, including any test data obtained, will be required. Lists of the properties which were satisfactory, partially satisfactory, and unsatisfactory, and a ranking of the relative importance of the properties in each of these categories will be requested.

2. A general evaluation of the effectiveness of the wood-plastic for the specific end-product, including the desirability of using WPC, will also be requested. Suggestions as to desirable improvements or modifications in WPC to increase potential applicability in their industry and the identification of other company products for which wood-plastics should be evaluated are also to be included.
3. Other information required will be company appraisal of (a) simplifications in manufacturing processes obtained by use of wood-plastics, (b) economic advantages and disadvantages of incorporating wood-plastics in end-products, and (c) potential volume of wood-plastics that may be used within the company and within the industry.

A PROGRESS REPORT ON A FEASIBILITY AND CONCEPTUAL
DESIGN STUDY OF THE WOOD-PLASTIC COMBINATIONS PROCESS*

J. H. Frankfort**

ABSTRACT

(The Vitro Engineering Company, after analysis of work by many contractors and evaluation of their own effort, has made a feasibility and conceptual design study of the wood-plastic combinations (WPC) process.] This study (1) indicated that sufficient data have been generated for the design of a pilot plant facility with a 200 lb/hr production rate; (2) recommended a pilot plant that would provide capabilities for development work on other monomer systems — work essential for design of a production facility using these materials; (3) considered the economic factors related to a 3000 lb/hr WPC production plant; and (4) concluded that the market potential for furniture, flooring, and specialty items is excellent. [Design features for monomer handling, impregnation, and irradiation equipment as well as research functions for the pilot plant are described. Recommendations and conclusions are presented.]

Vitro has made a comprehensive review of the work performed by Dr. James Kent of the West Virginia University, the work on vinyl chloride by Dr. A. M. Feibush of the Air Reduction Company, and the market survey report of Arthur D. Little, Inc. (ADL). We monitored the work performed by the Southern Interstate Nuclear Board (SINB) concerned with the commercialization of wood-plastic combinations in the southeastern area of the United States and reviewed the current proprietary work on wood-plastic combinations (WPC) being carried out by the Lockheed-Georgia Company, which is a company-funded program of research and development on wood-plastic materials. (Lockheed-Georgia, under a USAEC contract, also supplies limited quantities of wood-plastic material for industrial product testing.) Information supplied to us on the progress of the physical testing program being carried on by

*The work is being done under contract with the USAEC.

**New Projects Manager, Vitro Engineering Company, New York City.

the Research Triangle Institute and on the commercialization studies being performed by Pacific Northwest Laboratories, and the Western New York Nuclear Research Center also served as a basis of our considerations as to the feasibility of a pilot plant facility for the semi-production of wood-plastic combinations.

These wood-plastic combinations are made by first impregnating wood with a monomer and then polymerizing by using a radiation source and thus converting the treated wood to a solid polymer-reinforced material. The resulting product is a completely new and different product and has many characteristics that are better than those of wood. The new material, aside from having increased strength, moisture resistance, and dimensional stability, and improved machinability and finishing characteristics, has an extremely high esthetic value, being a much warmer and more colorful product than wood. Best of all, it requires no maintenance since the finish is not superficial and damaged areas can be restored to the original condition by a simple sanding or buffing process.

The process suggests the use of lower-grade woods for applications where only high-grade and selected woods are now being used. Many of our so-called non-furniture grade wood species offer excellent textural and esthetic qualities but are currently not being used because of their lack of hardness and strength, or because of poor finishing qualities.

Because these new materials have such attractive commercial possibilities, design concepts for both pilot-plant and full-scale production facilities for WPC have been investigated.

PILOT PLANT FACILITY

The construction of a pilot plant using methyl methacrylate (MMA) and with a semi-production capability of 200 lb/hr throughput is feasible, with very little additional process data required. The pilot plant would also provide capabilities for further development efforts on other monomer systems such as vinyl acetate, styrene-acrylonitrile, and vinyl chloride. The pilot plant would demonstrate all of the basic design elements of a full-size production facility.

Design Features

Let us first try to summarize design features required for a WPC pilot plant.

The pilot plant should have a capability of producing a reasonable quantity of samples of WPC to supply industrial needs for product development and test marketing. This limited production initially would be based upon methyl methacrylate wood formulations.

Monomer Handling. Because certain monomers such as methyl methacrylate must be deoxygenated before their use in wood plastics, and since dyeing of monomers is desirable, day-storage tankage for monomer treatment is required. In addition, because we believe that coloring of wood plastics is an important item in developing markets, we would include in the pilot plant some monomer stripping capability in order to obtain data on the dye removal from monomers.

It is probably unrealistic to assume that all monomers investigated in the pilot plant should be purchased and stored in tank-car quantities. We recommend that yard storage be provided for the monomer used for production runs of WPC and that drum storage and handling facilities be provided for all other monomers.

Impregnation. Since it is necessary to produce materials within a comparatively narrow range of specifications, the pilot plant impregnation equipment and procedures must provide scale-up capability to a full-size production plant. It is obvious that there cannot be any unresolved questions of impregnator equipment design at the end of the pilot-plant program. In particular, any problems arising in the use of closures and seals and in the loading and unloading of materials must be solved.

The impregnation system should therefore be designed to afford full flexibility to operate the system either under vacuum conditions or, where pressure impregnation is required, at pressures up to 250 psi. The system would be provided with attendant vacuum and pressurization facilities. A nitrogen system would supply blanket gas during the impregnation cycle, and the impregnators would be capable of handling the full production rate of the facility on a single-shift basis.

We believe that enclosed production carriers are essential; therefore, the impregnators should be designed to receive directly the loaded product carriers.

Product Carriers. Since the most important research function of the pilot plant is to provide scale-up data for the production plant, we propose that the product carriers be sized to approach production scale. For example, because it is expected that production plant packages will be about 8 ft high for good source efficiencies, we suggest that the pilot-plant packages be approximately 4 ft high. We would expect by experimentation to determine the effect of package height with sufficient detail to be able to extrapolate process conditions for a package height of 8 ft.

The product carriers for the pilot plant would be large enough to accept product 8 ft long, vertically stacked to a height of 4 ft. The product would be stacked in the carrier to ensure that there are individual vertical stacks of material, each approximately 1 in. thick with an air space of approximately 1 in. between each stack. There should be no more than eight 1 in. layers of material in each of the carriers to effect optimum photon absorption efficiency.

The product carriers must be designed to operate in a pressure range of from as low as 1 mm of mercury to 250 psi. They should not have any fixed supply, drain, or relief valves because the subsequent radiation would polymerize any contained monomer and render the valve inoperable.

The product carriers should be designed to include both a cooling water system for removing heat and an expansion chamber to moderate any pressure developed in the carrier during the time the polymerization cycle is passing through the exothermic region.

Since the impregnation and radiation operations require the product be maintained in an inert gas atmosphere, the product carriers must be sealed before removal from the impregnator.

Irradiation Facility. For a semi-production pilot facility which can provide scale-up information to full production, we recommend a cobalt-60 source rather than other sources of radiation be used because:

1. Sodium-24 is not generally available throughout the country.
2. Cesium-137 at present is too high-priced, and large-scale cesium-137 sources in the United States still must be evaluated.
3. Spent fuel elements introduce problems concerned with ownership and insurance; also there is no set price and, more important,

the sources are not generally available over the entire country for general industrial application.

4. A nuclear reactor not only has poor economic advantage but also has problems associated with third-party liability, licensing, and poorer material handling capabilities.
5. X-ray machines and accelerators are generally incompatible with the process requirements, and there is a lack of definitive price information, a lack of operating experience on this specific process, and a lack of response on the part of the manufacturers of the equipment.

The pilot-plant source arrangement should be capable of delivering low dose rates to the wood arrays to obtain the maximum radiation efficiency. The irradiation should be on a three shift/day operation. All other operations would be one shift/day. At 200 lb/hr production, the total yearly production can be 1.6 million lb, assuming 8000 hr/yr. Maximum dose rate is approximately 0.11 Mrad/hr; minimum total dose is 1 Mrad. Estimated residence time in the irradiation cell is 18-24 hr.

The source geometry and size would be governed by required dose rate, residence time, total dose, and photon absorption efficiency. Source configuration should consist of a plaque array which would present a suitable face area to the product carrier and a total length compatible with a simple materials handling system.

Within the radiation area there should be a source storage system to provide means of safe assembly of sources in the required array, a means of source redistribution and replenishment, and a method for rapidly removing the source from the radiation area to permit maintenance of the conveyor system when required.

Safety. It is well to recognize that the combined problem of chemical hazard and nuclear hazard will require extensive safety precautions and possibly auxiliary safety equipment. We would expect that early and continuing liaison with responsible licensing and regulatory boards would be required during the detailed pilot-plant design.

Impregnation and the subsequent transfer of the product carrier to the irradiation area of the plant should be done without exposing personnel to inherent explosion or toxicity hazards in handling the monomer.

The radiation area as well as all monomer handling and impregnation areas should be explosion proof. Moving parts in contact with other metallic surfaces should be spark proof.

An inert atmosphere within the radiation facility is needed. This will provide secondary protection against explosion or fire which might be caused by the rupture of the product carrier. The maximum oxygen concentration within the radiation area should not exceed 4% by volume.

It is possible that relatively large amounts of wastes will be generated in the pilot plant because of the nature of the research program. The pilot plant should be designed to permit the safe disposal of a wide range of monomers.

Research Functions

Monomer Studies. The pilot plant should provide the capability of doing research and development work on other monomers systems such as vinyl chloride which require high pressure during the radiation polymerization at room temperature. For these monomers we recommend autoclave-type carriers. We would expect the research and development program to be directed toward establishing the most economic operating conditions for the use of

these other monomer systems in wood-plastics manufacture to permit the determination of their process economics. We would expect to test-process all monomers, including methyl methacrylate, using the autoclave before undertaking any production runs.

Operating Conditions. The process research function of the pilot plant should be directed toward confirming the best operating conditions to produce the most uniform product. In any test run we would anticipate collecting the following data:

1. Temperature history at several places in the wood array to determine the maximum wood temperatures during polymerization.
2. Pressure history during irradiation polymerization.
3. Data, such as local polymer concentration, obtained from destructive testing of product.
4. Qualitative evaluation of product — color, uniformity, etc.
5. Dose distribution data throughout the wood array.

Each of the above data collections would be made for the different experimental source configurations and for each monomer-wood system. Items such as monomer losses from the wood-plastics, wood handling techniques, etc., would not be determined for every system but optimized for some common product system.

Product Development and Testing. To permit the widest application of wood-plastics from the proposed pilot plant, we recommend the inclusion of a well-outfitted woodworking shop and wood research area. This wood research area would permit small-scale product development work including glueing, fastening, and slicing operations. It should also provide a certain amount of test equipment for evaluating characteristics, and a process control laboratory.

COMMERCIAL PRODUCTION PLANT

Design Criteria

Heat Removal. During the polymerization processes, exothermic heat of polymerization is evolved in WPC manufacture. The wood can be considered to be a diluent, acting to absorb the heat of polymerization. It is obvious for most plastics and most loadings that some of the heat of polymerization must be removed from the wood-plastic system during polymerization if a satisfactory material is to be made. The problem of heat removal from WPC is so critical to the manufacturing process that the basic design of the production plant hinges on the method selected. Because the experiments supported by the USAEC to date have only been on a laboratory scale, the temperature problem has not been seriously considered.

Vitro has studied the heat evolution problem as it affects much larger quantities of polymerization material and its influence on the process design in detail. Any attempt to polymerize the monomer under isothermal conditions in the manufacture of wood-plastic composites is extremely difficult because it involves removing heat from a solid system. With further research, it might be possible to find a liquid in which the monomer-impregnated wood could be submerged during polymerization, with the liquid acting as a heat-transfer medium without affecting the product. Since we cannot assume the availability of such a medium, we must then explore the implications of solid-gas heat transfer. The most expedient solution to the problem is to polymerize WPC under such conditions (of radiation and heat removal) that the product temperature is permitted to rise to some set maximum temperature, perhaps 250° - 300° F.

Dose Rate. Wood-plastic irradiation differs from other irradiation processes because there is a distinct dose rate sensitivity in the total

dose requirements. It is the dose rate sensitivity of the material that has a major influence on the radiation source design. In discussing dose rate and source design for a production scale WPC plant we are limiting ourselves to a detailed discussion of a cobalt-60 source.

Kent's data show that WPC formed using low dose rates require the lowest total dose. In addition, the resultant polymer in the WPC has a higher molecular weight, which means polymers of higher quality. An even more important aspect of dose rate effects is its influence on heat evolution rates, since Kent also shows that the lower the dose rate the lower is the rate of heat generation. Since we are to take advantage of the latter effect because of our concern with the problems of heat dissipation in a pilot- or production-plant facility, we directed our efforts on source design to achieve this purpose. Machine calculations were made to determine the dose-rate variation through a uniform WPC array using a uniform plaque source of Brookhaven National Laboratory (BNL) type cobalt-60 strips. The results show that for an 8-ft-high source (for the proposed production plant) the maximum dose rate in the WPC is 0.157 Mrad/hr. It is this dose rate which in a two-pass system will define the minimum integrated dose received by the wood. Cobalt-60 with an activity of 1 curie/g in a BNL strip of 1.03 g/cm² of cobalt will deliver a dose of 0.064 Mrad/hr to the wood array half thickness. To achieve 0.04 Mrad/hr, a specific activity of 0.625 curie/g, i.e., 0.04/0.064, is required. These values are uncorrected for edge effects. In a continuous irradiation process, where product is moved past a source and parallel to it at a uniform speed, the total dose received by all points of the product in a plane parallel to the source is uniform. By properly spacing higher-specific-activity strips and by varying time, one can avoid the use of a dilute source with its attendant high encapsulation costs. Thus 15-30 curies/g source material will result in a source length of ~ 90 ft.

Economic Considerations

The criteria described above were used as a basis for estimating capital costs for a commercial wood processing plant. For a 3000 lb/hr WPC plant producing 24 million lb of WPC/year, the estimated engineering and construction cost is \$1,500,000. The source installation cost, which excludes the first-year replenishment, is \$832,000. Thus, the total investment for the plant is \$2,332,000.

The estimated capital costs for the project are:

Sitework and yard improvements	\$ 140,000
Administration building	45,000
Process building and equipment	750,000
Irradiation facility	365,000
Source	832,000
Engineering	200,000
Total	\$ 2,332,000

Table 1 shows the annual and hourly operating costs for this plant.

Table 2 shows the total costs for producing several special shapes and specific products.

Economic evaluations of product costs based on a 3000 lb/hr production facility indicate that the impregnation and radiation costs for the methyl methacrylate would be approximately 4¢/lb. Monomer costs for methyl methacrylate formulations would be approximately 8¢/lb. Total conversion costs (less wood cost) would be 13¢/lb, resulting in a cost/board foot of methyl methacrylate-wood combinations of 65¢ (excluding wood cost). Assuming average wood costs of 35¢/board foot, the total product cost (less marketing cost and profit) would be \$1.00/board foot. Assuming 100% markup for marketing costs and profit, possible selling price of methyl methacrylate-wood combinations is \$2.00/board foot.

TABLE 1. ANNUAL AND HOURLY OPERATING COST FOR MMA PLANT PRODUCING
3000 lb/hr WPC USING A 1.28×10^6 COBALT-60 SOURCE

<u>Annual Cost</u>	<u>\$ / yr</u>
Plant Depreciation ¹	\$ 150,000
Source	
Depreciation ²	83,200
Replenishment ³	116,480
Direct Labor ⁴	156,000
Factory Overhead ⁵	124,800
Maintenance Labor and Supplies ⁶	75,000
Utilities ⁷	15,000
Local Taxes and Insurance ⁸	30,000
Operating Supplies ⁹	7,500
Inert Gas ¹⁰	3,000
Third Party Liability	75,000
Total Manufacturing Cost	\$ 835,980
General Overhead ¹¹	167,196
Total Operating Cost	\$ 1,003,176
<u>Hourly Cost</u> (for 8000 hr/year)	125.20/hr
Use	130/hr for estimating

NOTES

¹Plant cost \$ 1,500,000 for 3000 lb/hr MMA - hardwood; depreciation 10% (new depreciation guidelines of 1963 U.S. Master Tax Guide gives 10 years of life in lumber, wood products and furniture manufacturing, 11 years for plastics manufacturing).

²Source 1.28×10^6 C Co-60 at 65 ϵ /C encapsulated \$832,000; depreciation 10%, since diffuse source elements can be moved closer together as source strength decays.

³Source replenishment: 14%/year at 65 ϵ /C.

⁴Direct labor:

Receiving, shipping and yard	3 man/day
Impregnator and irradiator	3 men/day (1/ shift)
Packing and unloading	8 men/day
Supervisor	1 man/day
Total	15 men/day = 120 man hr/day

Assume average \$ 3.50/hr

⁵Factory overhead: assume 80% of direct labor

⁶Maintenance labor and supplies: 5% of plant cost

⁷Utilities: 1% of plant cost

⁸Local taxes and insurance: 2% of plant cost

⁹Operating supplies: 1/2% of plant cost

¹⁰Propane: assume 6,000 scfm/hr inert gas ($N_2 + CO_2$) produced at 25% on stream for radiation cell; assume N_2 for impregnator

¹¹General overhead (excluding sales) 20% of total manufactured cost

TABLE 2. COST OF SPECIAL SHAPES

Item	Size and Weight (as WPC)	No. of items per carrier	Monomer Cost (MMA @ 21¢/lb) (70% loading)	Irradiation Cost*	Total Cost
Floor Tile	9 in. x 9 in. x 1/4 in. = 0.0117 cu ft = 0.803 lb	3200	\$ 0.0693	\$ 0.0394	\$ 0.1197/tile
2 in. ϕ cylindrical stock	0.0274 cu ft/ft 1.88 lb/ft	1530 ft	0.163	0.085	0.248/ft
Shoe Lasts	5 lb	384	0.43	0.33	0.76 ea.
Salad Bowl	0.053 cu ft 15 in. max. dia. x 4 in. high	488	0.312	0.259	0.571 ea.
Bowling Pin	5.1 lb (sic)	288	0.44	0.44	0.88 ea.

*At \$ 130/hr

RECOMMENDATIONS AND CONCLUSIONS

Pilot Plant

We believe that the 200 lb/hr plant could satisfy an initial requirement. We also feel that the pilot facility could, at a moderate additional capital cost, be designed to allow a 10-fold production increase (2000 lb/hr) as the demand became necessary.

After reviewing the work performed by the contributing contractors and supplementing the information with our own engineering evaluation, we conclude that there are sufficient research data available to proceed with the design and construction of a pilot plant facility having semi-production capabilities. The location, we believe, is of secondary importance since it will be a pilot plant and will not be required to produce full production quantities.

From the input supplied by ADL, SINB, and others and as a result of direct discussions with many potential users of WPC, we conclude that the pilot plant should be sized to accommodate materials as long as 8 ft.

Because of the possible severe heat-control problems involved in the polymerization of styrene-acrylonitrile (S/A) and vinyl acetate (VA), we recommend that the pilot plant production capability be limited to monomethyl methacrylate (MMA) WPC. The radiation source should be cobalt-60.

In the research program for the pilot plant, we recommend developing additional data on the S/A-WPC heating problem to determine the operating requirements for semi-production scale manufacture of S/A WPC. If it is established that radiation of the S/A WPC at 1 atm is satisfactory from a temperature standpoint, the pilot plant will be able to produce quantities of approximately 60 lb/hr.

Since vinyl chloride (VC) is very attractive economically for WPC, we recommend developing data in the pilot plant for its use in WPC even though a VC-WPC process plant must require some modest pressure technology.

We recommend that, unless VA-WPC have some outstanding quality, they not be investigated in the pilot plant. Difficulties in temperature control and dyeing of VA-WPC make them less desirable than the above WPC systems.

Further Research

The following recommendations for further research are presented, based on our findings to date.

The work by West Virginia University and Air Reduction Co. on vinyl chloride should be extended to determine which is better — unplasticized PVC*-wood, or plasticized PVC-wood.

Further consideration should be given to experimentation on the controlled non-uniform loading of wood products which may lead to the development of a new area of application. By impregnation of solid materials to a depth of perhaps only 1/8 in. or 1/4 in. and leaving the center unimpregnated, important savings could be realized by using less monomer, while still realizing most or all of the physical qualities of a uniformly loaded WPC.

Further experiments in radiation polymerization should be performed at dose rates lower than 0.4 Mrad /hr.

Further work should be done to extend impregnation techniques to include pressurization capability up to 250 psi.

One important experiment which should be carried out, in order to reinforce the basis of the proposed pilot plant approach, would be a large scale irradiation of a wood-plastic composite array approaching the size

*Polyvinyl chloride.

proposed in this report (4 ft high x 8 ft wide made up of a composite of 1 in. layers of WPC totalling 8 in. thick).

A mock-up of a thin-walled WPC container could be irradiated at a maximum dose rate of 0.11 Mrad /hr for a total residence time of approximately 18 — 24 hr. Temperatures could be measured at various points within the wood-plastic array, to check, empirically, our heat generation calculations.

Information which might be developed, and which would be of importance to the optimization of radiation energy utilization in a production facility, is more definitive data on the optimum "shape" of the energy source necessary to fully polymerize a spectrum of various monomer-wood formulations.

Commercial Potential and Facilities

Although product development efforts generally fall just outside of the range of scope of USAEC operations, the next phase of product development effort will be tied closely to process considerations. For this reason the pilot plant is of great importance, bracketing both areas of process and product development simultaneously. We believe that efforts toward the commercialization of this process should emphasize the great difference between wood-plastic combinations and wood or plastics in themselves. We have recognized a tendency by potential industrial users to compare the projected cost of WPC to either conventional wood or plastic materials. The product should be considered as a different material; its worth should only be evaluated on this basis.

From our discussions with potential industrial users of WPC, we conclude that the construction of WPC facilities should rest for the most part with material suppliers rather than the using industry. In addition to more or

less standardized configurations, such as sheets, boards, etc., which might be the major output of such a facility, some custom irradiation of specialty items will be required to simplify the blending of colors and textures of WPC materials (perhaps legs and trim to match tops).

Initially one of the largest potential applications for this new material may be the furniture industry. Input from this industry clearly indicates an overwhelming interest in veneer or laminated type materials rather than solid WPC materials and some interest in solid WPC for end trim and legs. We believe that a concerted effort should be directed toward the development of a veneer technology using WPC veneers, perhaps 1/8 in. to 1/4 in. thick. This would involve development work in the bonding of WPC laminates to wood-material backings such as plywood.

The market potential for specialty flooring applications appears excellent. Specialty applications for wood-plastic composites, such as sporting goods, institutional furniture, boat fittings, knife handles, salad bowls, etc. also show good marketing promise.

Information from ADL, SINB, and direct conversations with potential industrial users indicates a rather low level of interest in the structural properties of WPC. The physical properties of the materials such as hardness, abrasion resistance, mar resistance, and increased dimensional stability are of major importance to the potential user. A semi-production sized pilot plant is of extreme importance to the next phase of market development since the pilot plant would be capable of producing sufficient quantities of material to satisfy an industrial product testing program.

RADIATION AND ITS COMMERCIAL FUTURE

Ernest B. Tremmel*

ABSTRACT

The responsibilities of the Division of Industrial Participation of the U. S. Atomic Energy Commission are described and include the functioning as a focal point for industrial inquiries for civilian applications of nuclear energy. Peaceful applications of nuclear energy fall into two categories: (1) heat, which includes electrical power generation, and (2) radiation and its applications. Two applications that have been developed through government programs during the past five years are the radiation preservation of food, an area of great commercial potential, and wood-plastic combinations (WPC). With respect to the latter, three suggestions are presented: (1) WPC should be thought of as new products rather than replacements for existing products; (2) much greater effort in product imagination and in development of new markets needs to be applied; and (3) industry should accept greater responsibility in finding methods of getting these materials into new products and into use. The timely transfer of government-developed nuclear technology into the private sector of our economy is stressed.

I am very pleased to have this opportunity to speak at this information meeting on irradiated wood plastic materials. In order to clarify the relationship of our Division of Industrial Participation to the Division of Isotopes Development, who has sponsored this meeting with the Atomic Industrial Forum, I would like to briefly explain the responsibilities of our Division. We have been designated within the Commission to act as the focal point for industry; in other words companies that are interested in civilian applications of nuclear energy can contact or submit their inquiries to our Division and we, in turn, will answer their inquiries or refer them to appropriate people within the AEC. We also have the responsibility of

*Director, Division of Industrial Participation, U.S.A.E.C., Washington, D. C.

continually examining the work the Commission is carrying out in its own facilities under its operating contractors to determine when it is timely for this work to be moved to industry. We report to the Commission on how successful the program of transferring developments to industry has been and have a dual responsibility with our Technical Information Services to carry out a program of transferring technology of non-nuclear developments to industry. We also are the contact for the states and communities in regard to peaceful applications of nuclear energy.

Our program in the AEC on irradiated wood-plastic materials has been of particular interest to me not only from a technical viewpoint, but from the challenge it presents in developing techniques to transfer government-developed technology into the private sector of our economy. One can find proponents of various approaches in connection with these types of programs. For example, some people feel that the Government needs to do lots more work on irradiated wood products with taxpayers' dollars if we are ever going to get the private sector of our economy to utilize this technology. There are others of the school of thought that if the Government keeps supporting further research it will discourage companies from utilizing the technology because the Government research will develop advanced technology that will make their investments obsolete. I believe that the Commission, as a Government agency, has been somewhat unique and also successful in developing technology and then transferring it to the commercial sector of our economy.

PEACEFUL APPLICATIONS OF NUCLEAR ENERGY

I think it would be appropriate today to just say a few words about the development of peaceful applications of nuclear energy in general before I discuss specifically the areas of radiation applications. Nuclear energy, of course, was first utilized for defense purposes and in the early years very little time and money were applied to peaceful applications. This has gradually changed and I believe in this year's budget we have reached a point in AEC's existence where more of our dollars are being applied to peaceful applications than for defense.

Heat

I like to think of our peaceful applications as being divided into a number of areas and I like to think of the applications in terms of heat and radiation which are really the basic products of nuclear energy. In the application of heat, we have the areas of civilian power, maritime, and space applications. Also, our Plowshare program probably belongs in this category, involving as it does the controlled release of large quantities of energy. The other major area of application is the use of radiation, whether it be machine-generated or source-generated. In the area of civilian power (which includes, of course, desalting) — I pick this application because it is the area in which the Commission has probably concentrated the most — I believe we have been very successful in promoting its use in the private sector of our economy. The last few years have seen the use of nuclear power for central station power plants become attractive in many sections of our country. Last year at Geneva, the Commission updated its estimates of the growth of nuclear power from 40,000 Mwe installed in 1980 to 60,000 - 90,000 Mwe in 1980. The General

Electric Company, one of the large suppliers of nuclear power plants, has estimated 87,000 Mwe installed capacity by 1980.

The approach we have followed in transferring the technology from our Government laboratories into central nuclear power stations has been one that we have called our Power Demonstration Reactor Program. Actually the Government first built experimental plants, or we might call them proof-of-principles reactors, in our own laboratories. Following this stage, we entered into demonstration programs with utilities and manufacturers. As a result of this program, utilities are today building nuclear power plants without Government participation.

Another area that is presently attracting considerable attention is the use of reactors for propulsion of ships in our maritime program. There has been considerable discussion as to the best method to transfer this technology, that is the use of nuclear power in our civilian maritime fleet. This last year has been particularly interesting because several companies have strongly stated their ability and intention of quoting fixed prices with guaranteed performance for civilian maritime ships. Others have felt that it is more important for the Government to go ahead with a land-based test facility to assure that the technology is available on a reliable, safe, and economic basis. It appears that the path we will follow on this program will be to endorse both approaches, that is, encourage construction of reactors and direct ship application as well as carry out a strong government support program.

Since the use of nuclear power in our space and Plowshare programs is in much earlier stages of development, I will not take time today to discuss them. My remarks on the civilian power program and maritime

program are intended to stimulate your thinking about methods of moving technology from the Government laboratories or from Government-sponsored research into the commercial sector of our economy.

Radiation

The commercial use of ionizing radiation to improve the properties of existing products and catalyze the synthesis of new materials has been suggested and studied for more than a decade, but only in the last five years has the potential become a reality. The interaction of gamma rays and high-energy electrons with matter can catalyze chemical reactions, change the molecular or lattice structure of solids, and kill micro-organisms. Each of these types of radiation effects has been utilized by industrial firms to manufacture or process a number of products, and many companies are conducting experimental programs to further apply the beneficial effects of radiation to production operations.

Commercial radiation processing has grown very rapidly from virtually nothing five years ago to an annual volume of irradiated products with an estimated value of \$20 million in 1962, \$75 million in 1963, and about \$100 million in 1964. Radiation is used by industry to improve the properties of transistors and diodes, to crosslink polyethylene for electrical insulation and packaging film, to catalyze the synthesis of ethyl bromide, and to sterilize surgical sutures and other medical supplies. These radiation applications have resulted in many products sold commercially, but there is an even broader spectrum of industrial research and development of other irradiated products which we believe will eventually appear on the commercial market. One of the uses of ionizing radiation which is likely to become a commercial process is the radiation-curing of paints and other coatings.

Although this technique has been investigated by a number of industries, including automobile manufacturers, the first commercial use will probably be the curing of prefinished interior wood paneling by electron-beam irradiation.

Although the development of process radiation is today being carried out to a considerable extent by private industry, the federal government, of course, is still sponsoring considerable research and development of this technology. One such area is the production of composite wood-plastic materials by radiation-induced polymerization of monomers, which is under discussion today. We feel this is one of the most promising applications of process radiation currently being investigated. The intensive industrial interest in this process is certainly apparent with the attendance here today, as well as at many other information meetings.

Many other potentially commercial uses of ionizing radiation to process or synthesize materials are being investigated under contracts with our Division of Isotopes Development.

The preservation of food products by ionizing radiation is another area of great commercial potential that is presently being developed largely through government programs and which I am especially enthused about. Radiation preservation of food is of two types: sterilization and pasteurization. Radiation sterilization involves relatively high radiation doses and permits the long-term storage of the product at room temperature. It is of primary interest to the military for the preservation of rations, and the Army has conducted and is continuing an extensive program on the radiation sterilization of ham, pork, chicken, beef, and other meats. Radiation pasteurization prolongs the shelf life and retards the spoilage

of foods under normal refrigeration, and this type of radiation processing has the greatest commercial potential. The Atomic Energy Commission supports a major development program in this field, with main emphasis on pasteurization of fruit and fish, as well as the disinfestation of wheat and other grains. Studies of the economics of radiation preservation of food indicate costs of 1 - 3 cents per pound of fish and 1 cent or less per pound of fruit would be acceptable to the producers of these products. Radiation costs are within this range.

To test the large scale application of radiation to reduce spoilage in fruits, a high-capacity mobile irradiator will be operational shortly and will initially be used in the California area. Fruits such as strawberries, peaches, nectarines, and bananas will receive emphasis. Disinfestation of grain and grain products will be possible on a near-commercial scale with the completion of the Grain Products Irradiator in Savannah, Georgia, late this year.

The process radiation field has been growing rapidly and prospects for the future are encouraging. Because the field is so new in a commercial sense, it is impossible to predict the sequence or magnitude of future radiation applications, but potential industrial users have an increasingly realistic basis for evaluating radiation processing through the experience of existing commercial application.

In spite of any of our successes to date in carrying out our obligations under the Atomic Energy Act to develop peaceful applications of nuclear energy, difficult decisions have to be continually made by our Commissioners as to what the magnitude of the Government effort should be in specific areas. How far should we carry or fund technology before

industry will utilize it in the commercial sector? How long should we continue a research and development program before terminating our support because industry is not exploiting it? These are difficult questions, some of which we will face in the next few years on the program that is the subject of this conference.

There are a number of steps the AEC has been taking in the last few years to help achieve the early transfer of technology into use in the commercial market. We have in the past several years increased our liaison with industrial associations and especially with the Atomic Industrial Forum. This meeting today is an excellent example of the important contributions an organization such as the Forum can play in the interchange that must take place between the Government and industry if we are to successfully transfer technology.

In the last year the AEC has expanded our Advisory Committee on Isotopes and Radiation Development. The membership of this Committee has been gradually changed over the past year to bring to the Committee additional representatives from the various segments of the radiation industry.

We have now asked the Committee, of which Mr. John Kuranz is presently Chairman, to study the desirability of a cooperative demonstration program for selected applications of process radiation in which industrial firms would make a substantial contribution as a next major important step in this field.

Recently Dr. Laughlin M. Currie, then Chairman of the AEC Advisory Committee on Isotopes and Radiation Development, conducted a survey for the Commission to determine the extent of industrial development of isotopes and radiation, to identify factors that limited their use, and to obtain

recommendations on how AEC might better help this portion of the atomic energy program. The report was subsequently reviewed and approved by the AEC Advisory Committee and has been submitted to the Commission for consideration. The report reflected industry's views that a tremendous potential exists for expansion of routine applications of isotopes and radiation. The Commission is presently studying the report and recommendations to determine how the findings can be translated into policy which would improve prospects for the further expansion of industrial applications of radioisotopes and radiation. Here again our goal is not only to encourage the use of radiation, but also to assure a competitive industry.

Before closing, there are several thoughts I would like to leave with this audience. First, in connection with this conference today I would like to suggest that in the future we think of wood-plastic materials as new products instead of as replacements for existing products. I was pleased in this morning's discussions to note that several of the speakers had already taken this approach and were emphasizing new products for the use of wood-plastic materials.

Second, along this same line of thought, we need to apply a much greater effort in product imagination and in the development of new markets. This is an area where I think industry must take the initiative because it is not the normal role of the Government to promote new markets or market products. Furthermore, this is a natural role for industry and one of the areas in which industry is best suited.

Third, in my opinion, the time has come for industry to accept a greater responsibility in finding methods of getting these materials into new products and into use. There is no doubt that to a certain extent

what we are trying to do is to force a new technology into commercial use. I believe the Government's role should continue to be at about the same level and in the same areas as it has been in the last year. I believe the time has now come for industry to take on the challenge of building radiation facilities to develop their own products. Industry's views and suggestions should, of course, continue to be made available to the Government, but you must also analyze your own company's role to assure that your goal is not only to obtain Government research and development dollars, but that your main efforts are directed to develop a commercial market for new products that will be your source of income in the future rather than to have to try and obtain more Government dollars.

I am very pleased to be here today and particularly impressed by the interest shown at this conference in wood-plastic materials.

SUMMARY REPORT OF
RADIATION PROCESSED WOOD-PLASTIC MATERIALS

Martin H. Stein*

ABSTRACT

[A new family of wood-plastic products has been developed under an Atomic Energy Commission program. These products, which have enhanced physical properties and yet retain the esthetic appeal and other desirable characteristics of wood, have promise in many markets, e.g., furniture, floors, sporting goods, window frames, etc. Preliminary reports indicate that a production plant with a 3000 lb/hr — 8000 hr/year capacity could produce wood-plastic "blanks" at a reasonable cost. The Atomic Energy Commission's program for development and testing of wood-plastic combinations is also described.]

A new family of wood-plastic products has been developed in a program sponsored by the Atomic Energy Commission. These materials offer advantages over natural wood in a wide variety of uses. The product is a wood-plastic combination produced by impregnating wood with a monomer (a liquid plastic such as methyl methacrylate) and then irradiating the composite with gamma rays from a cobalt-60 source. The radiation polymerizes the plastic monomer molecules and yields a solid wood-plastic combination which

1. Is harder than natural wood by several hundred per cent—
thus more resistant to blows, scratches, etc.
2. Has much higher compression strength and abrasion resistance.
3. Absorbs moisture more slowly and therefore has more dimensional stability (resistance to warping and swelling).
4. Has much improved shear and static-bending strength.
5. Retains the natural wood grain and color, or can be artificially colored throughout.

* Chief, Process Radiation Section, Division of Isotopes Development, U. S. Atomic Energy Commission, Washington, D. C.

6. Can be sawed, drilled, turned, and sanded with conventional equipment, giving a hard, beautiful, satin-smooth finish.

The distinct advantage of this new process is that many of the properties of natural wood are improved without sacrificing the wood's important characteristics, including esthetic appeal.

These new products have promise in these and other markets:

Furniture (indoor and outdoor)	Decorative trim
Floors	Sporting goods
Window frames, sills, and doors	Boat decks and trim
Tool handles	Dies and jigs

Process methods for the wood-plastic materials have been steadily improved under the past three-year development effort. Experience with impregnation techniques using various monomers (methyl methacrylate, vinyl acetate, acrylonitrile, styrene, and vinyl chloride), radiation doses, and catalytic additives has disclosed several innovations having economic significance.

Preliminary reports indicate that a production plant, designated to produce 3,000 pounds of wood-plastic material per hour on an 8,000 hour per year basis, could produce wood-plastic "blanks" at the following costs:

UNFINISHED PRODUCT SHAPES	COSTS
1. Floor tile (9 x 9 x $\frac{1}{4}$ inch, each)	\$ 0.12
2. 2-inch-diameter cylindrical shapes (linear foot)	0.25
3. Shoe lasts (each)	0.76
4. Salad bowls (15-inch diameter- 4-inch height, each)	0.57
5. Bowling pins (each)	0.88

The above costs were based on a hardwood methyl methacrylate composition: 0.7 lb monomer per pound of wood. All costs, excluding wood and product fabrication, have been included.

The Atomic Energy Commission has been broadening its program on radiation processed wood-plastic combinations and is arranging for testing of products made of this material.

The following projects have been or are being supported by the AEC:

1. A basic study of the techniques for producing wood-plastic materials utilizing radiation is continuing at West Virginia University.
2. A market utility study which identifies uses for the new material has been completed by Arthur D. Little, Inc.
3. A conceptual design and analysis study to design a pilot plant and analyze processing parameters is being prepared by Vitro Engineering Company.
4. A materials evaluation program designed to test the materials for mechanical and chemical properties is being conducted by the Research Triangle Institute.
5. Three Regional studies are being made to determine steps which would lead to the commercialization of the process. These are
 - a. Southeastern United States—with special reference to the Appalachian Region by the Southern Interstate Nuclear Board.
 - b. Northwestern United States and Great Lakes Region by the Pacific Northwest Laboratory—Battelle Memorial Institute.
 - c. Northeastern United States, including New England and the New York, New Jersey, and Pennsylvania area by the Western New York Nuclear Research Center.

6. A program to have industrial wood-product firms evaluate wood-plastic material in final product form is being conducted by the Lockheed-Georgia Company.

Several AEC research reports listed below are now available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia, except where noted.

REFERENCES

1. J. A. Kent, A. Winston, and W. R. Boyle, Preparation of wood-plastic combinations using gamma radiation to induce polymerization: effects of gamma radiation on wood, annual report. U.S.A.E.C. Report ORO-600, West Virginia University, (March 1963). Price \$1.25.
2. J. A. Kent, A. Winston, and W. R. Boyle, Preparation of wood-plastic combinations using gamma radiation to induce polymerization, U.S.A.E.C. Report ORO-612, West Virginia University, (September 1963). Price \$2.00.
3. J. A. Kent, A. Winston, W. R. Boyle, W. Loos, and J. E. Ayres, Preparation of wood-plastic combinations using gamma radiation to induce polymerization, U.S.A.E.C. Report ORO-628, West Virginia University, (May 1965). Price \$4.00.
4. F. D. Iannazzi, P. L. Levins, F. G. Perry, Jr., and R. S. Lindstrom, Technical and economic considerations for an irradiated wood-plastic material, U.S.A.E.C. Report TID-21434, Arthur D. Little, Inc., (September 1964). Price \$1.00.

5. D. S. Ballantine, Use of gamma radiation to produce wood-plastic combinations, Isotopes and Radiation Technology, 1(2) 189-95 (Winter 1963-64). Available from the Superintendent of Documents, U.S. Printing Office, Washington 25, D.C. Price \$0.55.

POTENTIAL APPLICATIONS OF IRRADIATED

WOOD-PLASTIC MATERIALS

Buford B. Ruhl*

ABSTRACT

[The objectives of the Southern Interstate Nuclear Board-- (SINB) Wood-Plastic Combinations (WPC) project were to (1) define the steps necessary to achieve commercialization of the WPC process and (2) evaluate selected sites suitable for WPC facilities in the SINB region, with specific reference to the Appalachian area.] A multitude of technical, manufacturing, and marketing questions still remain unanswered; therefore, [further study of WPC is required before commercialization. Three specific actions were proposed to provide additional data and technology; (a) establishment of an AEC research laboratory for WPC; (b) continued direct support to private industry and universities for development contributions to the WPC process; and (c) initiation of specialized conferences to provide companies with information on how to get into the business of WPC production.] Further support of WPC development at this time by Division of Isotopes Development (DID) must not be construed as government interference with private enterprise; to the contrary, failure of DID participation in the WPC program constitutes a negative interference, and the WPC concept would probably die for want of support.

Mr. Bob Gifford, Executive Director of the Southern Interstate Nuclear Board (SINB), asked me to make this presentation because I happened to be project director of the Wood-Plastic-combinations (WPC) contract while in the position of SINB Deputy Director. He is unable to be here today because he is presenting the SINB annual program to the Southern Governors' Conference.

Objectives of the project were (1) to define steps necessary to achieve commercialization of the WPC process and (2) to evaluate select sites in the SINB region, with specific reference to the Appalachian area, suitable for WPC facilities. This region of project interest encompasses the seventeen states located in the southeastern part of the country; this is a very large territory.

*President, Pan American Consulting Corporation, Atlanta, Georgia, and Deputy Director of the Southern Interstate Nuclear Board (SINB).

In the course of project activities, we held several meetings on the subject at various locations, and these involved more than two thousand people from state-government agencies, universities, wood industries, chemical industries, and allied-product industries. The most knowledgeable and dedicated attendees to these meetings were called upon to serve the project as consultants, to make recommendations on technical aspects, and to present findings in line with the project objectives and scope of work.

A final project meeting was held July 20, 1965 in Washington, D. C., where eight of the consultants presented their conclusions of the five-month study. These presentations are now being organized into a final report to be sent within the next few weeks to the AEC for review.

The attempt to study the commercialization of WPC assumed unusual proportions. At the outset we approached the subject through the back door, moving to commercialize the new materials through user industries, and then studied the results of our efforts. This confronted us with a multitude of technical, manufacturing, and marketing questions. Attempts to solve, resolve, or avoid these questions continued through the period of project activities. Many questions remain unanswered and I am sure that they were not all answered today. Therefore, much remains to be studied about WPC before specific commercial applications will be put on the market.

On the other hand, the summarization of results from the SINB project should prove to be a significant contribution to the AEC program of WPC development. The findings should provoke a substantial movement toward detailed study of many potential product applications. I believe that, with continued and expanded support by the AEC, commercial

investments and consumer benefits will come forth in great abundance in a short time.

The project director focused his attention on the scope of work and daily routine while Mr. Gifford carried forward the many other functions of SINB and maintained a supervisory interest in project activities. This enabled him to see the broad implications and impact which the commercialization of WPC could mean to the region and the country. He was in a position to anticipate the overall needs of a national program from a more objective point of view.

In light of this, he sent a memorandum to Mr. Gene Fowler, Chief of the AEC Division of Isotopes Development, dated August 25, 1965. He asked me to read it to you today. The memorandum includes observations and recommendations, but does not represent his final judgement or long-range conclusions on the subjects discussed.

This memorandum will confirm certain points offered for your consideration during our discussion in Washington on August 4, 1965.

General

One must approach the continuation of efforts at commercialization of WPC on the supposition that the Atomic Energy Commission and others concerned have a strong conviction as to the value and potential of the process. The Southern Interstate Nuclear Board shares this conviction, predicated, in large measure, on reactions and experiences evaluated in the course of the recent study completed for the AEC.

This is a significant point since the action of the Atomic Energy Commission and the SINB has generated a great deal of

enthusiasm. This enthusiasm has developed to the extent of causing certain industries and groups to organize themselves for the purpose of launching immediate commercial ventures.

I feel intuitively that some of the action and intended action of these groups is predicated on a belief that the national effort will continue to provide improved and more reliable data in engineering, marketing, product performance, economics, processing, etc. This is not to suggest that the process is unsound at this juncture, but rather to point out that there are many answers yet to be gained before we can talk in terms of guaranteed performance and product integrity.

The work that preceeded the study by the Southern Interstate Nuclear Board was restricted to laboratory scale; consequently, it was necessary to promote the development of certain products to gain some insight into the commercialization potentials and also to precipitate actions within the industrial community to cause private investigations. We feel that there is a definite market potential and observe that the AEC has spent many more dollars and considerably more time on other commercial concepts which offered less promise of success.

As a matter of general philosophy, I favor the removal of government from private industry fields at every opportunity and to the greatest extent possible. However, in the matter of WPC, I am of the strong belief that the Federal Government will have to become more deeply involved before sufficient data and technology are available for private industry—and particularly small industry—

to move forward with a standard commercial justification and soundness. In this context, I propose three specific actions.

AEC Research Laboratory for WPC

This laboratory should consider concurrently the many processes, products, disciplines, and conditions for production of quality wood-plastic products. It should be recognized that while the work of Dr. James Kent was of immeasurable value in projecting WPC, the continued expansion of his operation would not lend itself to the kind of multiple investigations necessary.

Most of the work done to date has been with methyl methacrylate and with limited tests on loading, radiation exposure, and treatment technique. There are some serious questions to be answered about the other polyesters, the potentials of irradiators and accelerators, as well as adaptability of the process to surface treatment and controlled loadings.

I feel that establishment of a federal installation would best serve American industry because the findings within this installation could be considered public property, hence in the public domain, and make possible future activities by companies not financially or technically endowed to carry out extensive multipurpose research and development programs of their own.

The absence of such information would leave the destiny of WPC development in the hands of a few extremely large corporations which would set their own time schedule, recognizing that competition in the field was limited. At the same time, it would be possible for large, private industry to proceed with

any degree of acceleration desired in developing products, processes, etc. The two approaches are not mutually exclusive. There is a precedent. During the extended period when the AEC was developing power reactors, private companies such as General Electric and Westinghouse were acting independently in developing concepts of their own and, in fact, were selling reactors commercially.

For example, if the AEC had removed itself from the power field at the same point, comparatively speaking, as we now stand in the WPC area, there would have been no federal reactor development for power beyond the basic graphite or water-moderated reactors. It has just been within the last year that nuclear power, at a competitive rate of approximately 4 mills/kwhr, has been established in the Oyster Bay program. This occurred after about 11 major reactor concepts had been explored.

I feel that the WPC research laboratory might properly be placed at the Savannah River or Oak Ridge facilities of the AEC, thereby drawing on the use of vacant space, technical personnel potentially subject to cutback, and the multiple resources these installations can offer. This facility should be strictly a research and development operation with no production schedules. The only activity relating to production would perhaps be the laboratory-scale treatment of certain special wood-plastic combinations and certain special products offered for testing by private companies. It would be possible for private organizations to draw on the data developed at this installation and made available for their use. Private organizations could then further refine

a process or a product that might lead to a patented or trade-name item.

Private Industries and Universities

I feel that the Commission should continue its direct support to private industry and university groups with a demonstrated capability for development contributions to the WPC process.

This would assure that the total investigation would receive the benefit of capabilities and varying points of view only private industry and university sources can provide.

Specialized Conferences

There is an increasing number of companies and specially formed groups seeking definitive information on how to get in the business of WPC production. It is not practical for a group or a company to take a patent lawyer, a design engineer, a comptroller, a marketing specialist, a top management representative, a chemist, etc. to Washington to get the broad spectrum of answers required. It is suggested that a task force of specially selected persons able to speak on these many points be established for visitation with these interested groups. By careful scheduling and planning, it would be possible for this task force to do some "circuit riding" and consult with a number of interested companies in a short time.

Summary

In closing, may I express the feeling that the future markets and the questions of economics can best be handled by the individual companies, but they will not be able to make early judgement on

these important matters or on matters of cost for equipment, production, or operations without the benefit of more meaningful technology and better defined processes.

We are pleased to make these views available for your consideration. I shall be glad to elaborate on any points briefly covered in this memorandum and enunciate specific reactions from industries and other groups which serve to substantiate the positions reflected here.

I shall look forward to hearing from you with respect to the course taken by the Atomic Energy Commission in pursuing this important area of industrial interest.

If I can impose a little further on your time, I want to add a few observations from my experience as project director.

Looking back a few months to the inception of the WPC project, it is apparent that we now have a better understanding of the material characteristics, the processes of WPC production, the implications of product manufacturing, and the potential for commercialization. But, turning around to look ahead to the requirements of actual commercialization for any number of WPC products in the competitive market place, we see that only a short step has been taken in the right direction.

Before commercialization becomes a reality, a series of specific products or items must be proven on the production line. Consumer acceptance of the material characteristics and pricing must be established on a demonstrated basis. For each product thus evaluated, there will be different standards and procedures. The remaining work must be much

more detailed and pointed toward individual product types, and it will be tedious to perform. Yet, I believe the information gained to date and the potential rewards of success will encourage the necessary action of the AEC and the user industries.

The WPC process can involve many species of wood, each combined with one of a variety of plastics to form thousands of new alloy materials. Each new material represents a different set of properties with possible applications for several industrial products. Adding the factors of density loadings and color schemes to the process, the alternatives of WPC reach a staggering number.

Technical areas needing refinement are the material strength, stability, heat and electricity transfer properties, color or staining characteristics, heat bending, production forming, waste materials use, techniques of plastic impregnation, production costs per material type, and resistance to fire, chemicals, abrasion, insects, weather, etc. This list could be expanded to almost infinite proportions if one considers the vast number of product alternatives. The considerations are greatly reduced, however, in the evaluation of a single product.

We speak to you today as industrialists, hoping you will consider the potential use of this new type material. Reference is being made to all its characteristics and to all industrial interests of the nation. But, for your own sake, I suggest that you look at the WPC material from a strictly selfish point of view—to your own company products. Please do not be complacent, like so many industries are when new technology is made available. Simply review today's information back at the plant; then descend upon the AEC, or appropriate private and public organizations

to help your company adapt to use the material. Frankly, I believe the best product to come from WPC will be dollar profits to industry. That will be sufficient to inspire other good things for society.

Two sources of radiation were considered in this project — isotopes and machines. The isotopes are lasting and continuous sources which perform 24 hours per day with predictable cost factors and are capable of irradiating material in depth. Machines are flexible, turn on and off conveniently, and are mobile; however, they penetrate only to limited depths, and thus they will probably be used only for surface coatings or thin veneers. For WPC the two source devices are commercially compatible and mutually productive within their designed capabilities. The choice depends on the radiation characteristics required, processing costs, and product standards needed in particular applications.

Site consideration for WPC production facilities should be realistic. Suppose the materials prove useful to American industry, and I believe they will in the very near future. A multi-purpose plant to produce a variety of WPC materials of nonuniform dimensions would be justified in several locations, wherever a concentration of wood-product industries is located or a new industrial park could be established. Special industrial WPC production plants to fit the needs of a given industry would obviously be located where local demand would justify the investment, e.g. High Point, North Carolina for the furniture industry. Single-product plants with limited flexibility can readily be justified by an individual manufacturing company, since the relative costs of investment and production are reduced by the simplicity of design and operation.

Where do we go from here? Many remaining studies and testing projects have been indicated in the presentations today, and we should

proceed with them without needless delay or wasted efforts. Industry should get into the action so that the initiative developed this far will not falter and fade.

The AEC should increase its support and encouragement of this work; it introduced WPC and presently represents the focal point of technical and commercial understanding. Potential producers of WPC should use their resources and testing facilities to evaluate product applications which have a value to their companies. Pilot and commercial WPC production plants are urgently needed to provide the materials required for product evaluation, limited manufacturing, and market testing. These materials should be available at reasonable prices on a time schedule that will not inhibit interest.

The Pan American Consulting Corporation is very much interested in the field of WPC and is as much non-government oriented as any company in the country. The Southern Interstate Nuclear Board, I believe, has served the best interests of private enterprise in its particular assignments as any equivalent organization in the country. These matters can certainly not be the basis of any logical disagreement.

Although Federal Government interference with private enterprise is always a popular subject for discussion, any charge that the AEC Division of Isotopes Development (DID) would interfere with private enterprise by further involvement in WPC stretches the imagination beyond reason. The relative size of the DID program, with all stops pulled, is incidental compared to even a partial impact of WPC in the Nation's wood-products industries. On the other hand, if the DID fails to continue and increase its participation in the WPC program, its lack of action would constitute

a negative interference since the concept will certainly languish and probably die for want of direction and support.

WPC have only recently been introduced to the industrial interests of the country, and for their most casual consideration. Many technical and commercial questions remain unanswered. User industries will not move alone under these conditions to make the necessary determinations for commercialization of the WPC concept. A restriction or failure to expand the DID program of WPC would, in fact, represent a neglect of the assigned responsibilities, especially since considerable public funds have been spent to develop the technology and nurture the commercial interests.

Today, WPC promise a bountiful business opportunity for many quarters of private enterprise; hopefully even medium and small companies will share in the benefits. Those of us already familiar with the ramifications and technology of WPC have a chance to exploit this firsthand knowledge. But, this timing advantage does not carry with it any proprietary rights to the information available or any guarantee of business success in the field.

IRRADIATED WOOD-PLASTIC MATERIALS — COMMERCIAL POSSIBILITIES
IN THE PACIFIC NORTHWEST (AND THE GREAT LAKES REGION)

C. A. Rohrmann*

ABSTRACT

[One of the objectives of a study being conducted by Battelle-Northwest is the investigation of the commercial possibilities of the irradiated wood plastics in the Pacific Northwest and Great Lakes regions. In this investigation many wood processors were contacted and made aware of properties, production methods, and cost of wood-plastic combinations (WPC). The potential applications of interest include flooring of many types, furniture, veneers, and plywood shapes. The properties of WPC are well suited to these uses and many of the processors showed genuine interest in the new product and its manufacture.] As a result of a recent price reduction announced by the USAEC, the use of ^{137}Cs as the radioactive source is suggested for consideration in the design of future WPC irradiation facilities.

This is a report on part of a broader study, still in progress (as of October 1, 1965), being conducted by Battelle-Northwest at Richland, Washington, for the Atomic Energy Commission. It has as one of its objectives the investigation of the commercial possibilities of the irradiated wood-plastic materials in the Pacific Northwest and Great Lakes regions. The process visualized from the work by Dr. Kent at West Virginia University, the study by Arthur D. Little, Inc., and the pilot-plant design and analysis by Vitro Engineering was used as a basis for the study. This process involves impregnating a suitable wood specie with acrylate monomers and irradiating the combination with a gamma source to polymerize the monomer within the wood. No research, development, or laboratory work was intended under this contract.

The procedure for the study in the designated geographic area involved the selecting and interviewing of representatives of companies

*Chemistry Department, Battelle-Northwest, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington.

concerned with lumber, wood products, wood use, polymer chemistry, and radiation-source preparation. All companies selected had backgrounds and capabilities in wood technology. We are confident that the sample was representative and technically adequate.

In our contacts with these organizations, we reviewed potential products and the properties which make irradiated wood-plastic materials attractive and also discussed the present status and problems in the production of these materials. In this area we discussed the most recent information on costs including its relevance to competitive materials, the limitations of the process with respect to wood species and bulk dimensions, the problem of monomer depletion at the surface, and the status of test data on dimensional stability under practical conditions of use, maintenance, and weatherability. To avoid monomer waste, treatment of pre-shaped pieces at the site of the new impregnation and irradiation facility would probably be required, and the possible effects that this treatment of shaped pieces rather than lumber blanks might have on the manufacturing process or the user processes were discussed. The extension of process improvement studies to include veneers and plywood, the development of modifications which would involve cross-linking or grafting of the polymer to the wood cellulose, and the inclusion of fire retardancy properties were suggested in the course of these contacts.

Throughout these contacts a wide range of interest was noted, from none, particularly among those companies whose activities were essentially limited to lumber production, to very high in companies that had research and development on irradiated wood-plastic materials already underway for their own proprietary uses. Among nearly all of the companies contacted

there was a generally gratifying willingness to discuss the whole area of application and the specific potential uses of irradiated wood-plastic combinations as it might apply to their business.

The applications of special interest on which the study centered included flooring of various kinds, e.g., that for homes, gymnasiums, boats (decking), exteriors, box cars (to replace imported floor woods), and institutions where low maintenance, decorativeness, or appearances may be important; a variety of furniture; and decorative applications with emphasis on veneers and nearly finished plywood shapes. All of these applications use to advantage the improved hardness and durability, minimum or reduced maintenance, and, probably the most important, the in-depth finish texture and appearance of fine woods. Because of costs and lack of emphasis on appearance, the use of irradiated wood-plastic materials for bulky structural uses was not considered.

Except for flooring and veneers it appears unlikely that the commercial potential in the near future could justify the establishment of an impregnation and irradiation facility by a lumber producer or processed wood user. However, the potential of a multi-product processing business serving a group of customers would probably be large enough to justify such a facility. The magnitude of the flooring and veneer (plywood) business is so great that even a small fraction of the total, if converted to irradiated wood-plastic production, appears to justify the cost of an impregnation and irradiation facility. Certainly there is sufficient justification for further development leading to commercialization.

For some special products for the furniture industry, the large losses of monomer incurred in the shaping or forming of processed wood strongly suggests the treatment of pre-shaped pieces. For some operators this would probably entail a substantial change in the present business arrangements--introducing another agent into the total process. This agent would be required to provide this new service with efficiency to maintain acceptable economics.

Veneers (and plywood) of WPC are of great interest even with the inherent costs of the monomers and the treatment process. High-quality veneers converted to products of greatly improved hardness or durability can probably absorb the higher production cost; this cost may range from 10 to 20 cents per square foot. Because of the insufficient data there are uncertainties in monomer loading and processing costs for veneers. Dr. Kent's work¹ on the lower-vapor-pressure monomers greatly enhances the favorable prospects for a practical process for veneers by the avoidance of surface depletion of the monomer.

Several industries showed a strong general willingness to give consideration to joint participation in further developments leading to commercialization but expressed concern over the ways of maintaining proprietary interests in such arrangements. Although there could be no commitment from these discussions, the expressions of interest are regarded as significant and should be of assistance to the AEC in formulating further actions relating to a pilot or semicommercial production facility.

There was some interest in essentially all related wood industries, but the least interest shown was among the basic lumber producers; it is concluded that WPC would constitute too small an extension of their present

activities to justify consideration. The interested companies are strongly conscious of cost and quality; hence these are areas where much more data need to be provided, especially for veneer and plywood products. Interest in a few cases involves proprietary matters. There is general desire of industries to be kept informed of recent developments.

To date, emphasis has been on ^{60}Co as the irradiation source; however, recent announcements by the AEC concerning isotope pricing in view of Isochem's activities at the Hanford plant strongly suggests that ^{137}Cs should be considered as an alternative to ^{60}Co . The quoted price for encapsulated ^{137}Cs to be produced in a private plant appears to have been set to be competitive with ^{60}Co produced in government-operated facilities. Cesium-137 should therefore be strongly considered in the design of any future irradiation facility. It is interesting to note that France and other European countries, notably Russia, favor the use of ^{137}Cs , which ultimately will be recovered as a by-product from the reprocessing of power-reactor fuel elements.

In view of the general interest of industry there is little doubt that whenever the AEC invites proposals for industrial participation, industry will respond positively but under conditions which will preserve their proprietary interests.

REFERENCE

1. J. A. Kent, A. Winston, W. R. Boyle, W. Loos, and J. E. Ayres, Preparation of wood-plastic combinations using gamma radiation to induce polymerization, U.S.A.E.C. Report ORO-628, West Virginia University, (May 1965), p. 42. Price \$4.00.

THE INVESTIGATION OF COMMERCIAL POTENTIAL
OF WOOD-PLASTIC COMBINATIONS IN THE NORTHEAST

Douglas M. Egan*

ABSTRACT

In a study of the commercialization of wood-plastic combinations (WPC), the Western New York Nuclear Research Center has chosen to explore only the requirements for commercialization and has excluded studies of market potential and profitability. Identification of products and firms for which WPC seemed to offer promising applications, determination of interest in WPC expressed by firms, and recommendations of promising locations for WPC processing facilities were the major responsibilities of the investigation. Among the more promising applications for WPC considered in the evaluation were flooring, furniture, industrial patterns, and shapings and turnings. Cost considerations and plant siting are also considered in the evaluation. It is concluded that additional information on WPC properties and production is needed before definite results can be obtained.

By direction of the Atomic Energy Commission the Western New York Nuclear Research Center has been investigating the requirements for commercialization of wood-plastic combinations (WPC). This study has been restricted to the New England states and New York, New Jersey, and Pennsylvania. It is necessary to stress that this study is intended to explore the requirements for commercialization but not those for market potential or profitability. This choice is conditioned by the following considerations:

1. As representatives of the AEC, our interests are separate from those associated with a private organization in which market potential and profitability are of prime importance. Reflecting a public interest, we can merely try to identify the conditions which must be met if

*State University of New York, Buffalo, New York.

the production and sale of WPC are undertaken. The desirability of attempting to meet these requirements remains in the domain of private interests.

2. With a lack of substantive knowledge at the time the contract was undertaken, the choice of particular types of products for examination was quite arbitrary. An attempt has been made in this commercialization study to choose representative products reflecting the manufacturing character of the Northeast.
3. The study has been conducted by viewing WPC as a direct substitute for products now in existence. No attempt has been made to project markets in which WPC might be viewed as new products.

The three major responsibilities of our investigation are the identification of those products and firms for which WPC seem to offer promising applications; the determination of the nature and intensity of interests in WPC expressed by firms; the recommendation of promising locations for WPC processing facilities. Preliminary results of our investigations suggest the following tentative conclusions.

PRODUCT APPLICATIONS

Among the more promising applications for WPC are flooring, commercial and institutional furniture, industrial patterns and dies, and wood turnings and shapings. These were selected from a list of some 70 possible applications of wood-plastics to current wood uses. Four primary factors considered in this evaluation and selection were (a) improvements in WPC product characteristics over the characteristics of wood currently in use; (b) the feasibility and ease of using WPC in current production processes; (c) an apparent cost saving in the final product by using WPC rather than

current wood species; and (d) the size of the market for these products. Market size, which was determined only crudely, was based on census reports of the value of shipments by manufacturers. As a result, the final market value of these products is clearly understated. Representative market values and their changes with time are shown in Table I.

Table I. Value of Shipments by Manufacturers
of Selected Products in the Northeastern United States

Product	Thousands of Dollars			% Change
	1954	1958	1963	1958-63
Office Furniture	34,875	37,705	52,667	39.7%
Industrial Patterns	N.A.	N.A.	25,215 ^b	
Flooring	8,379	8,391	13,285	58.3%
Shapings and Turnings ^a	N.A.	39,347	52,045	32.3%

N.A.=Not available

a. Totals are for the entire U. S. for selected, appropriate products.

b. Includes nonwood patterns.

Source: U. S. Census of Manufacturers

Flooring

In strip flooring WPC appear to offer advantages where wood is desired for its esthetic qualities and where maintenance costs are significant for conventional wooden floors. The possible use of WPC for gymnasium and recreational flooring appears quite good.

Parquet flooring of WPC may become a useful product competitive with high-quality nonwood floors currently in vogue. The durability and decoration that can be achieved with WPC plus competitive cost are most important.

In both strip and parquet flooring there are excellent possibilities for substituting lower-cost woods for those now used.

Furniture

For commercial and institutional furniture products WPC offer the advantages of durability, abrasion resistance, permanence of finish, and nonsplintering characteristics. The major disadvantages to be considered include the added product weight and attendant freight costs. Perhaps even more important, the engineering problems related to staining and homogeneous coloring must be overcome.

Industrial Patterns

The market for products categorized as industrial patterns and dies is poorly defined because so much of this work is done in captive shops. However, 1960 estimates made by the U. S. Department of Agriculture indicated that 70 percent of wooden jigs, die models, and patterns were made of solid lumber, and the remaining 30 percent comprised plywood and hardboard. The volume for this application in the same year was approximately 71 million board feet; sugar pine was the most commonly used wood.

The continued concentration of heavy manufacturing in the Northeast suggests that this is a market worth further exploration. On an experimental basis the Western New York Nuclear Center has had considerable success in shaping models of soft woods such as balsam and then impregnating them. Limited experience indicates considerable savings both of preparation and cost of wood working.

Shapings and Turnings

This is perhaps the most difficult market to define because of the broad array of products it encompasses. All manner of handles, shoe lasts,

and wooden novelties and specialties may be included. Characteristics of dimensional stability, durability, and possible improved heat resistance are most important here. The major drawbacks to commercialization are the difficulty of achieving product-color uniformity and the small size and scattered location of manufacturers of these products.

Veneers

While the markets for veneered products are extensive, the cost of impregnation and irradiation and the existence of significantly competitive polymerization processes reduce the potential of WPC in this application.

COST CONSIDERATIONS

Cost analysis still requires much more detailed scrutiny. Based on the cost estimates provided by other studies, it is obvious that WPC products must incur sizeable incremental costs for impregnation and irradiation. These incremental costs may be highly variable depending on whether captive or independent WPC facilities are used and on the average percent of capacity at which the production plant operates.

Because of this cost factor the most likely markets for immediate exploration are those in which demand is not highly responsive to changes in price or in which product processing costs are a small percentage of final price. On the basis of these considerations and the generally low-volume output of plants producing specialty products, we conclude that this type of commercial market is most suitable for initial exploitation of WPC.

A most important element in the analysis of costs is the validity of the assumptions made in the cost study above. If, for example, a variable average loading of monomers in woods of different weight is assumed, then substantial cost differences are indicated. This is illustrated in Table II.

Table II. Methyl Methacrylate Costs* per Bd-Ft of WPC Relative
to Wood Weight and Load Factors

Wood Weight	Load Factor			
	50%	70%	100%	120%
<u>lbs/bd ft</u>	<u>Cents/bd ft</u>	<u>Cents/bd ft</u>	<u>Cents/bd ft</u>	<u>Cents/bd ft</u>
2.00	21.0	29.4	42.0	50.4
2.25	23.6	33.1	47.3	56.8
2.50	26.3	36.8	52.5	63.0
2.75	28.9	40.4	57.8	69.3
3.00	31.5	44.1	63.0	75.6
3.50	36.8	51.5	73.5	88.2
4.00	42.0	58.8	84.0	100.8
<u>**Monomer cost per lb WPC</u>	<u>Cents/lb</u>	<u>Cents/lb</u>	<u>Cents/lb</u>	<u>Cents/lb</u>
	7.0	8.6	10.5	11.5

*Based on 21¢/lb for Methyl Methacrylate

**Assumes no trim losses after irradiation

If less than an optimum wood array is available for the WPC facility, impregnation costs may be within a range of 60 cents to 90 cents per board foot.

THE INTEREST OF MANUFACTURERS

This is a particularly difficult area of analysis, and interest expressed cannot be accurately assessed until firms make tangible financial commitments for production on at least a pilot plant basis.

In our personal contacts with more than 75 firms a considerable amount of speculative interest has been evidenced. Historically, innovation

has been slow among wood manufacturers. This slowness, coupled with the small average size of the majority of such firms, implies that only those firms with access to capital funds and technological expertise will venture into this new area of manufacturing. At this time it is difficult to tell whether this would occur by the unilateral actions of individual firms or by joint ventures between firms matching knowledge of the wood industries with knowledge and skills in the required areas of technology. The overriding difficulty at this stage of the investigation is the dearth of definitive product knowledge because of the narrow limits within which cursory product testing has been confined.

SITING

The problem of plant siting raises an immediate question related to production volume. The bulk of wood manufacturers in the Northeast have such limited production that a captive facility for each manufacturer would be out of the question. Immediate consideration must then be given to a separate facility which could serve the needs of several firms producing disparate products. If the conservative assumption is made that only a limited portion of any manufacturer's annual volume of production would be treated, then the facility must be central to a rather large complex of firms.

Data on the specific location and size of wood manufacturers in the Northeast are scarce. From available information it appears that geographic concentrations of high-volume production are limited. Among the areas immediately considered as appropriate locations for general purpose facilities, only four appear reasonable. These include Western New York, Northeastern Pennsylvania, Northern New Jersey, and Southern New England. These choices were predicated on the appropriateness of products produced and a sufficient total volume of production in the region that a small portion

of this annual production would still meet the requirements for economic operation of a WPC processing plant.

CONCLUSIONS

In conclusion one additional comment is appropriate. Definitive results cannot be obtained in a study such as this without necessary additional information regarding product properties, useful monomers, and the curing process characteristics. Rather, it is hoped that direction can be given to the investigative and evaluative efforts of individual firms that may venture into production of this new product. The critical element in the final assessment of the commercial potential of WPC must be the willingness of private firms to bear the risk and cost of innovation. This willingness is a sine qua non that cannot be undervalued.

COMMERCIAL PRODUCTION OF WOOD-PLASTIC COMBINATIONS

Lawrence G. Barrett *

ABSTRACT

The American Novawood Corporation was incorporated in August 1964 and was the first concern to produce wood-plastic combinations (WPC) commercially. In addition to sample preparation, company-sponsored research and development, and supplying materials and consulting services, the company is heavily involved with the construction of a commercial-scale pilot-plant facility. A strong criticism of the continued support of the USAEC development program for wood-plastic combinations is presented: the AEC has adequately demonstrated the value of WPC and should therefore discontinue support and permit private industry to take both the natural business risks and the rewards of their efforts.

Whether you are customer or competitor, I welcome this opportunity to tell you something about the oldest company in this emerging wood-plastic industry and to tell you of some of the problems that we have had during the first year of our corporate life.

The American Novawood Corporation was incorporated on August 28, 1964 with the primary objective of commercialization of wood-plastic combinations known generally as Novawood. As a first step in this direction an information folder was prepared and distributed to several hundred companies in the wood-fabricating industry. The folder described Novawood, told of the basic process by which it was made, indicated the improved physical characteristics, and made suggestions as to potential uses. We also advised of the forthcoming availability of Novawood to manufacturers for test and prototype purposes.

Our company began production of Novawood materials late in 1964. These materials were produced using a nuclear reactor as the source of radiation and, as a consequence, materials carried very high unit prices.

*President, American Novawood Corporation, Lynchburg, Virginia.

The startup of this small-scale production operation marked the first time that wood-plastic materials were produced on a commercial basis using privately owned and financed facilities.

Since startup of our reactor-irradiation operations we have been involved with sample preparations, company-sponsored research and development, and supplying materials and consulting services under contract to the wood-fabricating industry. Work is continuing in these three areas, but in addition we are now heavily involved with the construction of a commercial-scale pilot-plant production facility. This facility will permit unit-price reduction factors of 10 to 40 below that of materials produced in our reactor operations.

We are presently developing quotations for production commitments of Novawood materials to be supplied from our pilot-plant production facility.

INDUSTRIAL DEVELOPMENT

It is our opinion that the development of the wood-plastic industry will come about through the establishment of several small- and intermediate-size plants located in close proximity to either large sources of basic lumber supply or large wood-fabricating plants.

Our company has spent considerable time and effort during the last year in the development of process improvements that lead to the production of higher quality materials at lower unit costs. The nuclear engineering experience of our staff has been put to particularly good use in the development of new irradiator concepts that have the promise of effecting substantial reductions in plant capital investment. It is therefore an objective of our company to develop cooperative arrangements with

manufacturers and suppliers who are looking forward to the erection of plants in appropriate geographical regions. Under such an arrangement, full advantage would be taken of the past year's production experience, our developed plant design and process innovations, and experience in pilot-plant production of the products of interest.

OVERSUPPORT OF THE WPC PROGRAM BY THE AEC

The last year has brought to our company all the problems normally associated with a new business putting out a new product. However, our problems seemed to have increased considerably because of the AEC's involvement in this new material. We are indebted to the AEC for the support they provided Dr. Kent in his work at West Virginia University. There is no doubt that without the work of Dr. Kent we would not be having this meeting today. During the last year we have seen an ever enlarging program going on within the AEC to stimulate commercialization of the wood-plastic field. Wood-plastic combinations are the first application of nuclear energy where a customer product is produced and consequently WPC materials are receiving considerable attention within the AEC. The AEC seems to be determined to push wood-plastic combinations until in their judgement a sufficient number of companies are engaged in competitive production of the material. It is this determined effort on the part of the AEC which has caused us, the first company to enter the commercial field, to suffer more than would be normally expected in the way of growth pains for a new company.

Our problems started with the choice of the corporate name. The AEC in its efforts to promote wood-plastic combinations had designated the material as Novawood and had requested the Patent Office to reserve this

name as a generic term for the entire field of irradiated wood-plastic combinations. We sought and received AEC approval to use Novawood in our corporate name and, indeed, at the time the AEC encouraged the use of the term Novawood, giving every indication that the term was available for public use, free and clear. A few months later a prominent manufacturer in the wood industry took issue with the AEC over the term Novawood and despite the fact the name had now gone into the public domain and received wide spread acceptance; the AEC unilaterally decided to "switch rather than fight" and thereby dropped the name. By this time our company had received wide spread publicity and we were already shipping materials under a composite trademark utilizing Novawood as a generic term. Since that time we have been involved in a continuing effort trying to preserve our corporate name and our composite trademark.

Having established commercial availability for the new material at test and prototype development prices, we were officially a going concern offering services and materials in a commercial operation. Despite the fact that materials could be purchased commercially, the AEC continued to produce and distribute materials upon request through installations and organizations operating under government funding. After we had been in business for several months, in routine discussions between industry and the AEC, the AEC was informed of the wood fabricating industries' reluctance to enter into research and development programs because of the high initial production costs. The AEC's solution to this was to fund the present demonstration program wherein manufacturers may obtain materials and consulting advice from a competitor of ours. This action caused us to substantially lower our prices to customers for test and prototype materials and to

absorb the difference in costs as a loss. This method of operation hardly provides encouragement to stockholders of a small company. Fortunately, there were a few companies who recognized the potential of the material and were willing to spend modest funds for adaptation to their product lines. These companies today are rapidly approaching the position of being able to put wood-plastic products into the market.

We have learned that over 185 companies have made inquiries to the AEC regarding participation in their demonstration program. About 85 of these will be selected as participants. We invite the 100 "rejects" to communicate with us and make known their interests and we will attempt to serve their needs.

Past practice of the AEC has been to injure us in our sale of materials on a sample and developmental basis. This is now over and in the future the wood industry will be concerned with the sale of the best material at the best price when production orders are being filled. However, the AEC is presently developing a budget wherein they may fund a pilot plant operation and it is at this point that we, as a company, must oppose such action.

We have been told by some potential customers that they see no justification in buying materials when the AEC will supply them without cost. It is obvious that if the AEC proceeds with its plans to fund a pilot plant, materials supplied under this giveaway program (or even in a so-called "full cost recovery" program) would harm private competition. Not only would this be a great hardship to the companies concerned but it is contrary to the precepts of our free-enterprise system. It would be utilization of public funds to permit the government to be in competition with

existing privately owned and financed enterprises.

Once an AEC supported pilot-plant facility has been built it will be extremely difficult to cease operations. Jobs will be involved and political pressures will be exerted to maintain operations as long as there is an incompletely examined wood-plastic combination. Startup of our pilot-plant production facility is expected to occur far in advance of any pilot plant to be built by the AEC. At such a time our facility should have sufficient versatility to handle any wood-plastic combination being considered today. We strongly object to any scheme or device which puts any company at a competitive advantage through the use of AEC funds, including the conversion of any presently owned AEC facility for use as a wood-plastic pilot plant or production facility. Such a conversion would constitute a major subsidy for our competition.

In conclusion we feel that our company has had the opportunity to serve as a "midwife" at the birth of a new industry. We ask that this industry be given the freedom of growth normally associated with our free enterprise system. We believe that the AEC has adequately demonstrated the value of wood-plastic combinations and at this point they should bow out of the picture to let those that are willing to take the normal business risks receive the rewards due them. We believe that the AEC should feel a sense of accomplishment upon hearing my remarks today—it has done its job well, but it should not overdo the job.

DEVELOPMENT-PRODUCTION PROGRAM FOR LOCKWOOD

G. M. Kalember*

ABSTRACT

Lockheed's development program for their wood-plastic combinations — trade name Lockwood — has included expanded effort on both the process itself and commercial applications. Two problems of expanded commercialization are choosing methods of marketing and defining the types of products and customers for Lockwood. Investigation of thermoplastic monomer systems, impregnation techniques, effects of dose and dose rates on polymerization, physical and engineering properties, and testing and dyeing methods are included in the technical development program. Lockheed now produces 6000 board feet of Lockwood per month on a development-production basis.

Lockheed initiated a company-sponsored development program in June 1964 to investigate further the new wood-plastic combinations (WPC) developed by Dr. Kent under a U. S. Atomic Energy Commission contract. We have named the Lockheed-produced product Lockwood, our trademark. This program was started after a preliminary investigation showed that Lockwood had interesting technical and commercial possibilities. The results of the initial development effort were very encouraging, and we have progressively expanded the program to a comprehensive effort which includes investigation of thermoplastic-monomer systems for Lockwood, wood impregnation techniques, effects of radiation dose and dose rates on polymerization, physical and engineering properties, and testing and dyeing methods. We have also devoted considerable effort toward developing commercial applications through cooperative evaluation programs with various wood-product industries. This latter effort led us to participate in the AEC competition that resulted in the contract discussed by Dr. Burford. We are continuing our internal program concurrently with the AEC contract work.

*Manager, Development Sales Department, Lockheed-Georgia Company, Marietta, Georgia.

While early results are encouraging, we still have many problems to solve and many areas to investigate before any substantial expansion effort can be initiated—this is where our efforts are now being directed.

For example, one of our problems is how to market Lockwood. At Lockheed, our marketing consists of a highly specialized force of marketeers who sell million and multi-million dollar products to a relatively specific market. This same organization is not geared to sell a product like Lockwood to an open market. We are looking at the establishment of a separate sales organization with possible distribution through jobbers or agents.

We are also trying to define and determine the many types of products and customers for Lockwood. Furniture manufacturers are obvious customers, and they are interested in Lockwood for use in both veneer and solid construction. Since both veneer and solid construction are possible with identical materials with Lockwood, it is of particular interest to the furniture industry. This is a very exciting potential.

There are many different monomers that look promising and we will continue research to find the best. To date, most of our experience has been with methyl methacrylate. Consideration of the entire process, product cost, and the resultant physical and esthetic properties strongly suggests that this monomer may be the major material for commercial production of wood-plastic—at least in the near future.

The beauty of Lockwood is one of its most striking and admirable qualities as all the pleasing variation of the natural wood grain is retained. However, the addition of color is frequently employed in wood applications. Color matching is a possibility. We recently had a request for Lockwood to meet a very strict color requirement, but our process has

not progressed to the point where we can guarantee color. We have worked with a number of plastic dyes that have proved successful. They have been used in large quantities and at various concentrations to produce a wide range of colors in specific wood types. To meet the anticipated requirements for color matching we are continuing our work with dye manufacturers.

Impregnation of the wood in Lockwood production follows methods similar to those employed in the treatment of wood with conventional preservatives. We soak the material until a relatively high degree of impregnation is achieved, which results in a very desirable product because a uniform finish is produced throughout. With our heavily impregnated soft woods, weights are increased over 100 percent, while with hardwoods, weights are increased by approximately 60 percent. We are also working with methods to product desired properties with lower monomer loadings, another important area of investigation being conducted at Lockheed. Since the cost of monomer is a large portion of the total cost, lower monomer loadings could show considerable cost improvements.

For some applications, price is not a factor. One of our customers told us that using Lockwood to replace their present material reduced the cost of an operation from \$35.00 to \$1.50. I am sure for that customer even our development-production price was low.

There may be other places where Lockwood will be useful and also offer a considerable cost reduction to the user, and we shall continue to look for these applications. Our research and development will be maintained to answer questions concerning Lockwood properties. We will continue our work with the wood-products industry, furnishing Lockwood for

their use in making products for review and evaluation, and we expect this effort to furnish many answers to current questions.

For the next few months, we will be considering the possibility of building a production facility similar to the one discussed by Harry Frankfort of the Vitro Engineering Company. At the present time, at our Lockheed-Georgia Nuclear Laboratory, we are producing 6000 board feet of Lockwood per month on a development-production basis — and we can double this by adding another shift. Whether or not we go ahead with a Lockwood production facility will depend upon the results of our studies and our success in finding customers for our development production. We are enthusiastic about Lockwood, and within the next few months, we will know how enthusiastic.

THE OPPORTUNITY FOR COMMERCIAL USE OF
IRRADIATED WOOD-PLASTIC MATERIALS IN THE
FURNITURE INDUSTRY

Paul E. Rumbaugh*

ABSTRACT

[The Kroehler Manufacturing Company has prepared an occasional-table sample with half of the top of conventionally lacquered oak and the other half of wood-plastic combination. Dealer response to a demonstration of finish resistance to cigarettes and some common household liquids was good. A large sample of hard maple impregnated with dyed methyl methacrylate had little uniformity of color; however, a cocktail table of this material was beautiful, although lighter and more varied in color than several of this firm's Early American styles.] The wood worked well with conventional tools and machined cleaner and better than conventional maple. Predrilled holes were required for screws to prevent splitting. [The maple WPC glued well with polyvinyl adhesive, moderately well with urea resins, and excellently with fortified urea resins.] Early results with WPC veneers were, in general, disappointing but not necessarily pessimistic. The use of WPC for solid-wood furniture may be prohibited by cost except for some specific applications. [The greatest possibilities for WPC in furniture appear to be in veneer applications, but further research work is required in their fabrication and finishing techniques.]

The subject of my discussion today is "The Opportunity for Commercial Use of Irradiated Wood-Plastic Materials in the Furniture Industry." I represent the Kroehler Mfg. Co., World's Largest Furniture Maker. Let me caution you at the outset that my remarks and comments and all the testing we have done are from the view of the furniture manufacturer. We are grateful to everyone who has permitted us to take part in this general program—the Atomic Energy Commission, the Southern Interstate Nuclear

*Vice President, Kroehler Mfg. Co., Louisville, Kentucky.

Board, and Lockheed. We have been participating for quite some time both in meetings and through the use of samples which have been obtained with the help of these various organizations. Again, thank you for the opportunity to explore this exciting new wood-plastic product.

The best way I know how to tell all of you wood workers and other interested people what we at Kroehler have done, what experiences we have had, and what we have learned is to trace our experiences and our research on this product from the outset.

We were originally contacted by a consultant from Arthur D. Little, Inc. We spent several hours answering his questions and discussing the possibilities of wood-plastic combinations (WPC). I would like to point out, our comment at the conclusion of that initial meeting was that we thought the use of this product in solid woods would be extremely limited due to economics. We thought the greatest possibility would be in veneers and that the prospects were quite exciting and would be revolutionary if successful.

We attended Interstate Nuclear meetings later and obtained some southern pine which had been processed and irradiated at Lockheed. Our interest at this point was to find out what our dealer reaction would be to a furniture product made with special wood-plastic materials.

We duplicated an occasional table from our Country Life group. Part of the top was made from the processed southern pine lumber, and the balance of the top was made from Appalachian oak solids and Appalachian oak veneers. The oak materials were given our conventional lacquer finish. We took this historic table to the Southern Furniture Show at High Point, North Carolina. This is one of the shows at which furniture manufacturers

show their new items and new groups to a cross section of furniture dealers from across the country. This is where our thousands of dealers come to buy. We had a rather elaborate demonstration set for our dealers to show that the new wood-plastic type materials in the table were tough and extremely resistant to cigarettes, liquors, alcohol, finger nail polish and all common household detergents. With the same table we were able to demonstrate what they knew would happen with cigarettes and these various other materials on standard lacquer finishes. The dealer reaction was very good, with comments such as "wonderful," "great," and "really." This gave way to "cute" remarks such as, "Will it grow hair?," or "Will it make me bald?"

I want to point out at this time that we had no real fear expressed by any of our dealers when they were told the wood was made through the use of atomic energy. We feel that the word "atomic," for advertising and publicity purposes, is a plus item.

Our furniture dealers are very astute men. They are used to gimmicks and promotional ideas used by the industry to get them to buy particular products. We are in a very competitive market and the dealers initial excitement and cute remarks gave way to sincere questions as "when?," but more important, "How much will it cost?"

The next point of interest occurred when we received about 60 or 70 board feet of rough hard-maple lumber that had been impregnated with methyl methacrylate and irradiated at Lockheed. I want to mention also that all the equipment used in handling and testing these woods was of a mass-production type, that is, the type we use every day in our manufacturing processes. This hard-maple composite dressed very well through

the planers with conventional steel knives. The methyl methacrylate had been dyed and we had hoped to get a uniform brown Early American type color. However, there was little uniformity in color, although it was all darker than natural maple. Within a single board the color varied as we cut through it. We will not attempt to explain this color variation but pass along the information.

Next we tried various adhesives to make sure that when this material was processed, the adhesives would do a satisfactory job. Polyvinyl adhesive appeared satisfactory and was used in the assembly work. Standard urea resins were tried for "gluing up" lumber, that is, for making the solid top out of small segments and for gluing heavier legs, etc., from four-by-four lumber. Standard urea resins were only moderately successful so we turned to a fortified urea resin which gave us excellent wood failure. I might add that we did have a little latent glue line failure in two of the legs which we were unable to explain.

The wood routed, shaped, turned, bored, and sanded very well and was smooth and rich looking. Actually the processed wood machined cleaner and better than conventional maple that had not been treated. In assembly, everything worked well and polyvinyl glue seemed to do the job; however, we had to bore holes for screws. Screws driven directly into the wood without boring split the maple. We do not use nails in our furniture but I am sure the WPC could not be nailed satisfactorily without splitting.

We processed the maple and reproduced a Kroehler Cape Cod Early American occasional cocktail table. The finished product was beautiful indeed but lighter and more varied in color than normal Early American styles. We presented this table, through Governor Hulett Smith of

West Virginia, to Dr. Glenn Seaborg at a Washington, D.C., meeting of the Southern Interstate Nuclear Board. This table represented a lot of effort by a lot of people and a milestone in the peaceful use of atomic energy. We later presented a companion table to Edward T. Breathitt, the Governor of Kentucky, who is extremely interested in the prospects of future growth of industry through the use of these processes.

Following this particular project, we attended other meetings. We continued to stress the belief that for the furniture industry the success of WPC lay in the area of veneers, rather than in solid woods.

Through information we had received at the various meetings, we were led to believe that the irradiation of veneers might pose a considerable problem. It occurred to us that we might be able to impregnate and irradiate a veneer log prior to slicing. If successful, this would give us veneer already processed after it had been sliced. We sent veneer log samples to Lockheed for treatment. It was not too surprising that this was not successful. Since veneer logs are wet—that is, not kiln dried—they are unable to withstand processing without deterioration of the wood structure. In the irradiation process the wood samples split too badly for slicing and we discarded this idea and approach, at least temporarily.

Our next project was treatment of veneer. We sent Lockheed samples of walnut, pecan, oak, cherry, butternut, gum, poplar, and pine veneers. They were processed by Lockheed and returned to us. Unfortunately we do not know the loading percentage of these veneer samples, nor does Lockheed have any such record.

The results of this veneer testing were not satisfactory. The veneer had particles of methyl methacrylate crystals adhering to the

surface in various spots which, of course, would cause a defect in plywood. The crystalline material would have to be removed prior to any plywood manufacture. In addition, there appeared to be a thin film of material over all the veneer surfaces. We feel this film hurt the adhesion properties of the veneer in the gluing process. The veneer was wavy and curly, particularly at the ends. It was also stiff and split on the ends. Handling was difficult if we were to avoid additional splitting.

To get samples for experimentation involved very high waste, as we had to cut off all the ends which were split and wavy. The color of the veneer in each of the species was noticeably darker than normal veneer. Each specie of veneer spliced well in our tapeless splicers with conventional urea resin glues. We tried cold pressing these veneers into plywood with conventional urea resin adhesives. The adhesion was poor with the cold pressing method. Hot pressing with standard urea resins gave us only fair bond. We turned to fortified resins which cost approximately four times as much as our conventional adhesives. These worked successfully and the glue bond was satisfactory.

We were interested in the possibility of weight loss in the hot pressing of WPC veneers and found about a 2 to 4% decrease in weight when veneers were heated to approximately 230° F for four minutes. The loss was probably water but possibly some of the methyl methacrylate was lost also. The veneers, after fabrication into plywood, sanded reasonably well, except that they were not uniform in their sanding qualities. This we believe is due to a variation in the plastic loading from section to section. Resistance to stains, burns, and household materials was not satisfactory nor nearly as good as similar testing on solid wood.

One of our great problems in the furniture manufacturing business is instability of wood, so we tested the veneers and solid maple under conditions of high humidity. Normal veneers expanded twice as fast as treated veneers. Solid maple expanded four times as much as did the treated solid maple in our testing.

In general, results of the veneer samples were disappointing; however, we are not pessimistic. We recognize that this is the first attempt, at least the first attempt in which we have been involved.

We look forward with considerable interest to further research in veneers. Also, finish techniques need further development to meet the requirements of the furniture industry.

I would like to conclude by restating that the cost of irradiated solid woods is probably prohibitive for furniture manufacturing except for some applications. Certain interior frame parts in upholstered furniture need extreme strength not obtainable in standard wood. Or, for example, door frame rails in china cabinets need as much strength and dimensional stability as possible. Posts in desk knee-hole sections require extreme toughness.

Success with WPC can, of course, create extensive new industries and most certainly would revolutionize the furniture industry.

POTENTIAL OF WOOD-PLASTIC COMBINATIONS
IN THE SPORTING-GOODS INDUSTRY

Thomas R. Harris, Jr.*

ABSTRACT

[Wood-plastic combinations (WPC) have been used to prepare test samples of both baseball bats and golf-club heads. Improved impact strength, moisture resistance, and hardness have been observed on these test samples; in addition, golf-club heads had good gluing properties with epoxy adhesives. The increased weight on WPC can easily be compensated for in golf-club heads by using fewer lead weights; however, weight addition is of concern in baseball bats. Durability and appearance of bats are good because the finish literally goes all the way through the wood. With golf-club heads, the use of dyed monomers to eliminate finishing materials and operations would be desirable.]

I shall discuss briefly the potential commercial uses of irradiated wood-plastic combinations (WPC) in the sporting goods industry. I am associated with Hillerich & Bradsby, the major producer of baseball bats for the past 82 years. I am sure you are all familiar with our famous trademark, the "Louisville Slugger." We have also manufactured equally fine golf clubs for the past 50 years, sold through pro shops under the trade name of Power-Bilt and through retail stores under the trade names of Louisville Slugger, Grand Slam, Bobby Nichols Louisville, etc.

As you are aware, sporting goods products generally are subject to rather hazardous service. They must be designed primarily to withstand high impacts and weather conditions, yet maintain beauty or eye appeal. This is probably best exemplified by golf-club woods and baseball bats, but it is also true of other sporting goods which could be made of wood-plastic materials, such as tennis rackets, skis, hockey and lacrosse sticks, croquet sets, billiard cues, and bowling alleys.

*Hillerich & Bradsby Co., Louisville, Kentucky.

Because the design requirements are generally the same for all of the sporting-goods products, I will confine my remarks only to golf clubs and bats, in the following areas:

- (1) design requirements
- (2) test results we have achieved
- (3) increased cost as related to value added
- (4) potential commercialization of these products

BASEBALL BATS

The design requirements for baseball bats, besides styling, in order of importance are:

- (1) weight
- (2) impact strength
- (3) moisture and water resistance
- (4) hardness or compressive strength
- (5) appearance or finish

Weight is controlled by design or dimension of the bats, as well as by selection of particular timber. For example, northern white ash is used in baseball bats and some select hickory or pecan is used in softball bats.

Major-League bats require dimension control to $1/64$ in. and weight control to less than an ounce of a ballplayer's specifications. Balance or feel is of prime importance with bats, golf clubs, and tennis rackets. There is no permissible way to correct weights of bats by drilling or leading to meet specifications. Weight addition is of concern when we consider the use of impregnants.

The first bats made of irradiated wood-plastic felt as if they were weighted with lead. However, the initial impregnation technique was a conventional 60% loading of plastic. We feel this loading can be reduced and hope that the other design requirements we are looking for will still be met.

Impact strength is also important. Ballplayers, of course, are disappointed when a bat chips or separates along the spring wood-growth layer in the barrel section of the bat. Naturally, the professional ballplayer who plays daily becomes attached to a bat which has given him good performance. The magnitude of impact has been calculated, from the weight of the ball, the speed of the ball (over 100 mph), and the weight and speed of the bat (also approximately 100 mph), to be a force of 1000 to 2000 psi.

The spring wood-growth layer, which carries sap up the tree during the spring, is the weakest portion of the ash and this layer is where failure occurs, particularly when the ball is caught on the bottom portion of the barrel or when the ball is topped.

Handle breakage occurs when a ball is hit either on the handle or out on the very end of the bat and is due to the bending stresses that are set up. The bat, when swung by the stronger players, will bend up to 3 in. when the ball contacts the center of percussion. Professional players rarely complain about handle breakage because they realize that when this occurs the ball has not been contacted close to the "sweet spot" or center of percussion. Breakage is also caused frequently by hitting against the grain. Thus treating the barrel portion of the bat to eliminate chipping takes precedence over the problem of handle breakage. In

fact, we seriously doubt that we will ever try to impregnate the handle considering the inevitable reduced resiliency.

Our tests so far show a great improvement in impact strength of the barrel portion of the bat with the use of WPC. We also found extremely good stabilization or moisture resistance. Hardness of the wood was improved. Of course the durability of the finish and appearance are good because the finish literally goes all the way through the bat.

We feel encouraged enough from initial work to continue our testing and development of WPC. The main problem that remains is to determine if reduced plastic loadings which are within our weight specification will improve impact strengths sufficiently.

GOLF CLUBS

Basically, the heads of wood golf clubs must meet the same design requirements as the bats, but with the addition of gluability.

The wood specie universally used for solid wood heads is persimmon, which is botanically a white ebony. Persimmon is extremely hard and resists impact failures fairly well, with the possible exception of the neck of the head where the wood tapers to a thin feather edge surrounding the shaft. However, golf heads must withstand even higher impacts than bats — in the range of 2000 to 3000 psi when contacting a golf ball — and are subjected to more severe moisture conditions.

The wood head includes a plastic- or fiber -face insert, metal sole plate, lead weight, and screws, none of which will swell with moisture. The moisture problem is sometimes further compounded by the placement of wet head covers on the woods and the storing of the clubs in hot car trunks where summer temperatures reach as high as 150° F. This causes alternating wetting and drying cycles.

One of the first golf clubs made using irradiated wood-plastic was left unfinished and without an insert to see how well it would perform. On the other hand, a club which has a finish applied presents a much more attractive appearance. As you realize, appearance of golf clubs is extremely important.

Some of the next test work we would like to see will involve using colored monomer impregnants to determine if we can achieve an attractive finish to eliminate the need for both finishing materials and finishing operations.

Our test work so far shows extremely good stabilization, improved impact strength, improved hardness, and good gluing properties with the use of epoxy adhesives which are normally used to secure the insert and shaft to the wood head. We also found that WPC machine and sand well with conventional woodworking tools.

Weight control of golf clubs requires exact weighting to within 1/16 of an ounce, which is equal to 1 point on a swing-weight scale, or the difference between a D-1 and D-2 swing weight. This is equal to the weight of only one paper dollar. Because lead weights are added to achieve a precise weight, the irradiated wood-plastic is satisfactory, even though it is heavier since it merely requires less lead to meet normal weight.

SUMMARY

The design requirements for products in the sporting-goods industry certainly vary from those required in the furniture or hardwood-plywood industry. However, if WPC prove useful in sporting goods, which in many ways are subject to more abuse than household items, they should perform

well for most wood or veneered products. Each product will have different design requirements. The additional cost of WPC must be comparable to the value added and may possibly increase the selling prices. Immediate use will be seen in products where increased production costs can be amply recovered by an even greater value added to the product, provided, of course, the consumer is willing to pay for the improved product. Certainly a customer should be willing to pay more, say 10%, for a product that will last 50 or 100% longer.

The potential commercialization of WPC in the sporting-goods industry looks extremely good at this time.

POTENTIAL COMMERCIAL MANUFACTURE AND USE
OF HARDWOOD PLYWOOD PLASTIC COMBINATIONS

Clark E. McDonald*

ABSTRACT

[The market for U. S. hardwood plywood for 1964, exclusive of captive production, was 3.667×10^9 sq ft and was valued at $\$441 \times 10^6$. The largest portion of this market was for wall paneling, both prefinished and unfinished, followed by furniture, flush doors, mobile homes, and flooring. For these applications, wood-plastic combinations (WPC) of hardwood plywood would have many advantages — ease of cleaning, ease of repair, better appearance, resistance to staining and marring, etc. Probably the greatest potential for WPC would be for external applications — siding, doors, park benches, etc. — where conventionally treated woods cannot resist weather damage.]

It is my understanding that participants here today are more interested in the commercial opportunities associated with wood-plastic combinations (WPC) than in the technical details of their development. Therefore, the scope and emphasis of my remarks will cover the applications where I believe WPC may find utility in the manufacture of hardwood plywood and the end uses I foresee.

USE OF DOMESTIC HARDWOOD PLYWOOD IN 1964

Table I shows a breakdown of the hardwood-plywood market for the United States in 1964. Captive production, i.e. plywood produced by furniture manufacturers for use in their own production, is not included in the table.

*Managing Director, Hardwood Plywood Manufacturers Association, Arlington, Virginia.

Table I U. S. Hardwood Plywood Market — 1964

Material	*Shipments, sq ft	*Value, dollars
Veneer core — domestic	1,575 x 10 ⁶	270 x 10 ⁶
Other core — domestic (Lbrcore, particle board core, etc.)	73	43
Container and packaging — domestic	73	5
Imports from 38 countries	<u>1,946</u>	<u>123</u>
Total	3,667 x 10 ⁶	441 x 10 ⁶

*Does not include captive production.

The principal uses for hardwood plywood are for wall paneling, doors, mobile homes, furniture, and block flooring.

Wall Paneling

The market for prefinished hardwood plywood has developed from essentially nothing 15 years ago to over 1½ billion square feet in 1964, including both domestic and imported materials. Wall paneling constitutes 52% of the total market with 41% prefinished and 11% unfinished. Fifteen years ago only corporations and the wealthy could afford solid lumber paneling that was finished on the job. Today, practically anyone can afford some kind of hardwood-plywood paneling. Prices at the retail lumber dealer range from \$4 for a 4 ft x 8 ft prefinished lauan panel to ~\$40 for walnut or teak.

Customer Preferences. The housewife wants a prefinished wall that is "carefree." If a child smears lipstick, Vicks, or butter on the walls,

the mother wants to be able to wipe it off without damage to the finish or the wood. If a panel becomes scratched or nicked, repairs are difficult with some presently used finishes; but with WPC the scratch or dent can be smoothed with steel wool or sandpaper and the original color and sheen restored.

Some customers like the wood grain but also like pastel colors (not necessarily wood colors). One of our members who manufactures 50,000 $\frac{1}{4}$ -in. x 4-ft x 8-ft panels per day (principally lauan) finishes the wood in ten different pastel shades — pink, lime, blue, etc. By means of dye incorporated with the monomer, these pastel colors can be imparted to the paneling which will still retain the natural wood grain and a satiny sheen.

Application. One of the reasons for the growth of the use of plywood paneling over lumber paneling has been the ease of installation. A much larger wall space can be covered in a shorter time with a 4-ft x 8-ft panel than with 8-in. pieces of lumber. However, the plywood must be nailed or stuck with mastic to the studs or furring strips. Many homeowners are "do-it-yourself" remodelers and they do not have carbide-tip tools. The hardwood-plywood manufacturer would have to predrill nail holes in the WPC panels to prevent splintering or shattering the panel while nailing. Even panels installed with mastic are nailed at the top and bottom of the panel. The WPC panels can be bonded with epoxy glue but this is hard for the homeowner to handle. The retail lumber dealer must have saws to cut the WPC panels for fitting around windows and doors.

Doors

A flush door is usually made of two pieces of $1/8$ -in. hardwood plywood separated by stiles, rails, and a core material. There were over 15

million of these flush doors manufactured in the United States last year, and their one-half billion square feet of plywood accounts for 14% of the total market. A WPC door would almost certainly have to be machined in a factory that would have the tools to handle this material.

Unions do not like factory prefinished, precut, predrilled building materials. This is already posing a problem in some areas for the home-builder who is buying, for example, "ready-hung doors." The unions want to machine the doors for hinges and locks on the job site rather than having it done at a factory 500 miles away.

Mobile Homes

There is a growing demand for $\frac{1}{4}$ -in. and 3/16-in. wall paneling for mobile homes, and this use is about 5% of the total market. Much of this paneling is printed rather than prefinished. The printer takes an inexpensive specie, e.g. lauan, gum, cativo, and actually prints a grain on the face veneer to simulate walnut, teak, or some other expensive specie. The same large prefinisher mentioned earlier prints lauan in 15 different patterns and colors. If WPC plywood's cost can be kept low enough it could enjoy some of this market.

Furniture

Cut-to-size plywood for furniture, television, radio, and curved pieces makes up 23% of the total market. Earlier today Mr. Paul E. Rumbaugh of the Kroehler Manufacturing Company discussed potential commercial uses of WPC in the manufacture of furniture. You may have seen end tables and occasional tables made of WPC material by Kroehler and Stanley Furniture Companies.

One of the furniture markets that hardwood plywood has been losing to plastic laminates, marble, and glass is that of tops for motel and hotel furniture. Unfortunately, hardwood plywood will char if a burning cigarette is left on it and it will spot and ring where a glass of bourbon and water has been sitting. Motel and hotel owners have tried to eliminate the damage from carelessness of the traveling public by buying furniture with tops that will withstand these hazards.

We have tried to meet the competition of plastic laminates with "Finishield." This is a product developed by the Fine Hardwoods Association combining aluminum foil under the face veneer and a very excellent finish. "Finishield" will withstand the cigarette, alcohol, and water hazards, and we hope to recapture some of our markets with this product.

WPC plywood is resistant to staining and water absorption and cigarette burns can be sanded out. A scratch on a plastic laminate cannot be repaired.

Unfortunately, once plastic laminates were used on the top of a piece of furniture, the laminate manufacturer began pushing his product for the sides and fronts of cabinets, for kitchen cabinets, and for wall paneling. They have simulated the wood grains, simulated the wood feel, and even have oil finishes so that it now takes an expert to tell a simulation from the real wood.

According to the Arthur D. Little study, WPC could be competitive in price with Formica.

Laminated-Block Flooring

Prefinished $\frac{1}{2}$ -in. x 9-in. x 9-in. three-ply oak laminated-block flooring, which accounts for about 3% of the hardwood-plywood market, is

popular in multistoried apartment houses, garden apartments, and homes built on concrete slabs. One of the problems of all flooring, including solid lumber and resilient tile, is denting of the surface by ladies' spike-heel shoes. Perhaps WPC flooring could solve this problem.

I understand that parquet floor tiles cost 12¢ each to treat. Our product costs approximately 50¢ per square foot installed.

Miscellaneous Uses

Bowling Alleys. Bowling alley gutters made of curved plywood could use the abrasion resistance of WPC. The end of a bowling alley where the automatic pin spotter puts the pins gets severe use. Lam-N-Hard Division of Hoover Ball & Bearing Company has a continuous press that applies heat and pressure for manufacturing hardwood plywood that can stand up to this use.

Fire Retardant Panels. If a monomer could impart fire-resistant qualities to plywood panels a great market for WPC would be opened. The Federal Housing Administration and Building Code officials are most interested in such a plywood panel. However, the WPC panel would still have to compete in price with other wall-covering materials.

POTENTIAL OF WPC HARDWOOD PLYWOOD

The new WPC must compete with other conventional wood treatments, for example, (a) Compreg, wood impregnated with a phenolic resin and compressed; (b) Impreg, wood impregnated with a phenolic resin but not compressed; and (c) Stapac, wood heated under controlled moisture conditions and compressed. Compreg, Impreg, and Stapac could possibly be replaced with WPC plywood as dimensionally stable carving wood for die models and pattern making. Other potential uses include ladies' shoe heels, golf-club

heads, gunstocks, bowling pins, tool and cutlery handles, salad bowls, toys, brush blocks, ash trays, arms of school chairs, and desk tops for school furniture.

The greatest future application of WPC hardwood plywood would be for exterior uses where present-day finishes cannot resist weather damage. These uses would include exterior siding, exterior doors, garage doors, park benches, stadium seating, boat panels, and decks.